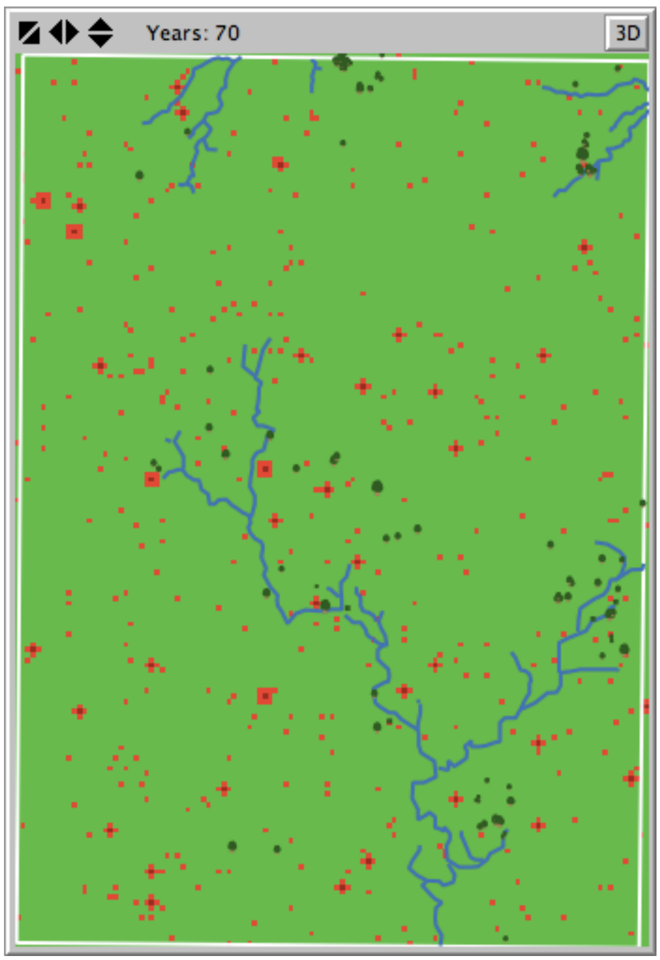
# USER MANUAL

*for the*

# BIG-LEAF MAHOGANY GROWTH & YIELD MODEL





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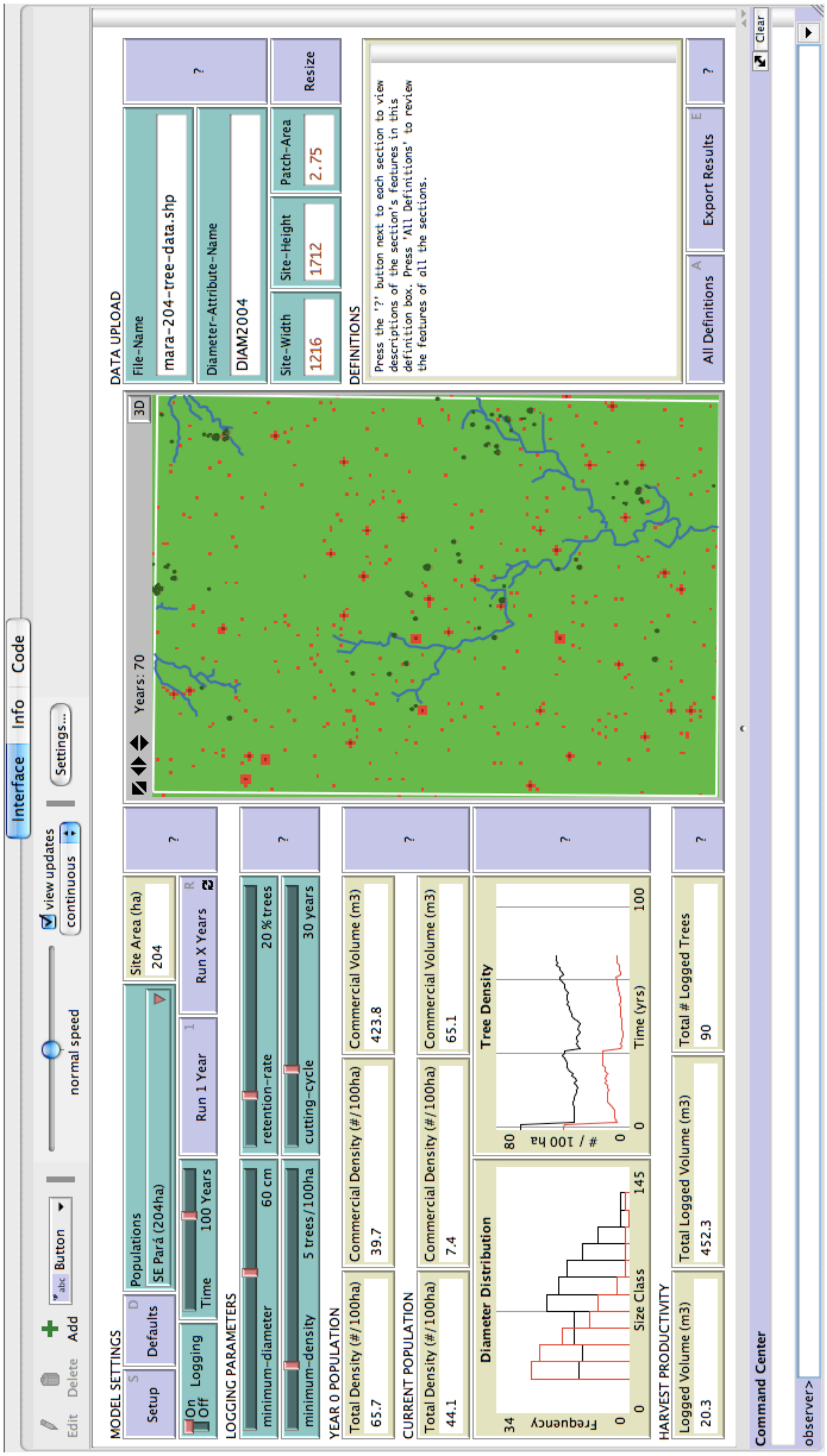
*On the cover: A big-leaf mahogany population (204 hectares) in southeast Pará after 70 years of simulation. Dark circles represent mahogany trees, sized according to diameter. The red squares represent disturbances with the darker red portions representing the zone of recruitment. Seasonal streams are shown in blue and the site boundary is shown in white.*




**Model Schematic**. The model interface as it appears when installed on your computer.

# Table of Contents

# 1 MODEL INTRODUCTION

In recent decades big-leaf mahogany, *Swietenia macrophylla*, has been intensively harvested across its natural range in tropical South America. Future timber production from natural forests will depend on protection and stewardship of surviving commercial populations through sustainable management practices. The Big-Leaf Mahogany Growth & Yield Model presented here projects population recovery and timber production from simulated harvests of mahogany in the Brazilian Amazon. The model offers forest managers a computer-based tool for assessing the impact of current management practices on both pre-installed example mahogany populations and on user-entered populations. Although the model was developed based on mahogany population dynamics in Brazil, it can offer useful insights into post-harvest recovery by natural populations throughout South and Central America. The growth & yield model uses the NetLogo 5.0.3 (Wilensky 1999) platform and can be installed on computers using Windows or Mac OS X operating systems.

The growth & yield model functions (algorithms) are derived from demographic data collected annually during 1995–2010 for nearly 600 mahogany trees and many thousands of seedlings, saplings and pole-sized trees at multiple field sites in southeast Pará and Acre. Model simulations can be run with or without harvesting. Under logging scenarios, the model harvests (kills) trees at specified intervals. During intervals between harvests, surviving individuals grow, reproduce, and die at rates observed in field studies. Harvest simulations are based on current legal management practices (60 cm minimum diameter cutting limit, 20% commercial-sized tree retention rate, minimum 5 commercial-sized trees / 100 ha retention density, 30-year cutting cycle). Forest managers can input mahogany population data from field inventories in order to project recovery and production outcomes following multiple harvests. Harvest parameters can be changed to view population and timber production outcomes under alternative management scenarios by adjusting one or more of the four management practices.

The model interface allows harvest simulations to be set up and run by clicking on a series of buttons as explained in the sections to follow. For a given starting population and harvest scenario, each 'run' will yield a different outcome (number of trees and commercial volume harvested, surviving density, etc.). This occurs because the model functions for survival, growth, and reproduction are recalculated each year using a random error term, leading to different long-term outcomes. For this reason, average outcomes from multiple simulations will best represent long-term population recovery and production rates for a given population and harvest scenario.

During each time step (year) of model simulation, the following actions occur on the model interface: (1) the time display advances 1 year; (2) trees grow in size on the landscape (trees are sized according to diameter); (3) trees are logged and removed from the landscape at specified harvest intervals; (4) trees die and are removed from the landscape; (5) the landscape experiences disturbance (red circles = disturbance; dark red = zone of recruitment); (6) trees reproduce and new seedlings are added to the landscape; and (7) disturbances are removed from the landscape and the plots and monitors are updated.

# 2 MANUAL GUIDE

This User Manual is intended for both beginning and advanced users working with the Big-Leaf Mahogany Growth & Yield Model to inform management decisions. The Manual can be read from front to back for a thorough understanding of how the model works. It can also be queried with specific questions using the section guide below.

***MODEL INSTALLATION*** (**section 3**) details the model installation process.

***HELP BUTTONS*** (**section 4**) explains where to find help while working in the model interface.

***A BRIEF GUIDE*** (**section 5**) provides basic instructions for navigating the model interface.

***MODEL SETTINGS*** (**section 6**) describes example populations available for simulations and how to setup and run the model.

***LOGGING PARAMETERS*** (**section 7**) explains how to adjust the four logging parameters that determine how the model harvests and grows a population over multiple cutting cycles.

***SIMULATION RESULTS*** (**section 8**) describes the monitors and charts on the model interface that track harvests and populations during simulations.

***USER DATA UPLOAD*** (**section 9**) provides instructions for uploading user data into the model framework.

***EXPORT SIMULATION RESULTS*** (**section 10**) explains how simulation results can be exported to text files for analysis and synthesis.

***SIMULATION EXPERIMENTS: BehaviorSpace*** (**section 11**) provides directions for running repeat simulations of a single harvest regime or multiple simulations of varied harvest regimes.

***ADVANCED USERS & NETLOGO RESOURCES*** (**section 12**) reviews the advanced NetLogo features and identifies resources for interested users to learn more about NetLogo programming.

The remaining sections review model features in greater detail and can be read in advance or when specific questions arise. If you still have questions after reading this User Manual, or have any feedback on the model, please contact the authors (**section 17**).

# 3 MODEL INSTALLATION

## 3.1 Web Installation

The following section explains how to install the NetLogo software from the 'Big-Leaf Mahogany in Brazil & South America' website and how to run the model using the software.

***Step 1. Download Model Package from Website***

Please visit our website to download the growth & yield model and to learn more about our research: http://www.swietking.org

The model can be downloaded from ***THE MODEL*** page on the website (http://www.swietking.org/model-applet.html). Download the zip-file appropriate for your operating system (Windows, Mac OS X, or Linux). The zip-file contains the files necessary to install the NetLogo software and run the model on your computer. Left-click on the link to download the file to your default download location. To specify a different download location, right-click on the link and select the *Download Linked File As* option.

***Step 2. Unzip Model Package Contents***

The contents of the model zip-file must be unzipped using built-in zip software. On most operating systems, double-clicking the zip-file accesses the zip software. However, some systems may require you to right-click the zip-file and select the 'unzip' or 'uncompress' options. Follow the unzip instructions for your software and extract the *Model* folder anywhere on your computer.

***Step 3. View the Model Folder Contents***

If you successfully unzip the zip-file, you will see the *Model* folder. This folder contains all the files necessary to install the NetLogo software and run the growth & yield model. Double-click the *Model* folder to view its contents. It contains seven elements:

(1) *Growth & Yield Model* file
(2) *Installation Guide* file
(3) *User Manual* file
(4) *NetLogo* folder
(5) *Data* folder
(6) *User* folder
(7) *Results* folder

The *Growth & Yield Model* file is the NetLogo file (.nlogo) containing the growth & yield model. This file will only run after installing the NetLogo software.

The *Installation Guide* file gives instructions on installing the NetLogo software and the Growth & Yield Model. It is identical to ***MODEL INSTALLATION*** in the User Manual (**section 3**).

The *User Manual* file is the User Manual for the Big-Leaf Mahogany Growth & Yield Model.

The *NetLogo* folder contains the NetLogo 5.0.3 installer necessary for your operating systems. This folder also contains the *NetLogo 5.0.3 User Manual* written by the NetLogo design team.

The *Data* folder contains all the data files necessary to run the growth & yield model. NEVER ALTER OR REMOVE ANY FILES IN THIS FOLDER.

The *User* folder contains example user upload files. These files should be viewed as templates when uploading your own data into the model framework. You will place your data files in this folder when uploading your own tree data (**section 9**).

The *Results* folder is the recommended destination for all results exports and is the default destination for certain BehaviorSpace simulation results (**sections 10 & 11**).

***Step 4. Install NetLogo 5.0.3***

Double-click on the *NetLogo* folder to view its contents.

If you are using a **Windows** computer, double-click the *NetLogo5.0.3Installer.exe* installer file.
If you are using a **Mac OS X** computer, double-click the *NetLogo 5.0.3.dmg* installer file.
If you are using a **Linux** computer, double-click the *NetLogo-5.0.3.tar.gz* installer file.

The installer file will open when double-clicked. Follow the installation instructions to install the NetLogo software on your computer.

If you would prefer to download the NetLogo software from the NetLogo website, download NetLogo 5.0.3 here: http://ccl.northwestern.edu/netlogo/5.0.3/

DO NOT USE ANY OTHER VERSION OF NETLOGO. THE MODEL ONLY WORKS IN NETLOGO 5.0.3. Refer to the *NetLogo User Manual 5.0.3* if you require additional assistance.

***Step 5. Open Model NetLogo File***

If you have successfully installed the NetLogo 5.0.3 software on your computer, you are ready to open the *Growth & Yield Model* file. Double-click the *Growth & Yield Model* file to begin using the growth & yield model on your computer.

If you use Mac OS X, a blank NetLogo file may open instead of the *Growth & Yield Model* file. This is a known Mac OS X – NetLogo bug and may commonly occur on your computer. It is easily resolved: simply leave the blank NetLogo file open and double-click the *Growth & Yield Model* file again. This will always open the *Growth & Yield Model* file correctly.

## 3.2 Online Model

The online version of the Big-Leaf Mahogany Growth & Yield Model can be accessed from the following website: http://www.swietking.org/model-applet.html. The online model is identical to the computer model except that it cannot: (1) upload user data files; (2) export simulation

results; (3) run **BehaviorSpace** experiments; (4) follow instructions from the **Command Line**; or (5) resize the landscape elegantly.

The online version of the model cannot upload user data or export simulations because of the limitations of our web server. **BehaviorSpace** experiments and **Command Line** queries can only be accommodated by installing and running NetLogo on your computer. The online applet only runs the features kept on the model interface. It does not support any NetLogo services occurring outside the interface.

The interface landscape can be resized in the online version of the model but this feature is more difficult to manipulate online than on your computer. The online model will not resize the landscape to a new **Patch-Area** if the blinking mouse-cursor is still in the **Patch-Area** input. Click anywhere within the online interface to remove the blinking mouse-cursor from the input (clicking in another input is an effective strategy) and click **Resize** to resize the model landscape.

These issues will be resolved if possible. Please sign up to receive updates on the model and our research on our website: http://www.swietking.org

### *Java Versions*

The Big-Leaf Mahogany Growth & Yield Model applet requires that your web browser support *Java 5* or higher. The correct version of *Java* can be obtained following these directions:

- Windows users (Vista, XP, or 2000) can download the *Java* browser plug-in from here: http://www.java.com/en/download/windows_manual.jsp
- Mac OS X users require version 10.4 or higher. No plug-in is necessary.
- Linux and Unix system users need the *Sun Java Runtime Environment Version 5* or higher. This is available for download here: http://www.java.com/. Check your browser's homepage for more information on installing the *Java* plug-in.

If you think you have the right browser and plug-in but the online model still does not work, check your browser's preferences to ensure that *Java* is enabled.

The following website may be helpful for determining which version of *Java* you have and for getting the correct version installed and running: http://www.javatester.org/

### *Browser Memory*

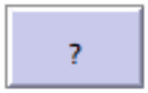
The Big-Leaf Mahogany Growth & Yield Model applet may require more memory than the browser normally makes available. This is more likely to happen when simulating large populations.

On Windows, you can increase the available memory ('heap') space in the *Java Control Panel*'s applet runtime settings. In the *Java* tab of the *Java Control Panel*, view the *Java Applet Runtime Settings*. Enter the following in the *Java Runtime Parameters* field: *-Xmx1024M*. Include the initial hyphen ('-') but not the final period ('.'). More information is available here:

http://download.oracle.com/javase/1.5.0/docs/guide/deployment/deployment-guide/jcp.html

Mac OS X 10.4 users should note that Mac OS X 10.4 initially had a low memory limit for *Java* applets (~64 megabytes). A *Java* update from Apple raised the memory limit to 96 megabytes. This update is available through the *Software Update* but no other options for increasing the *Java* memory limit are available.

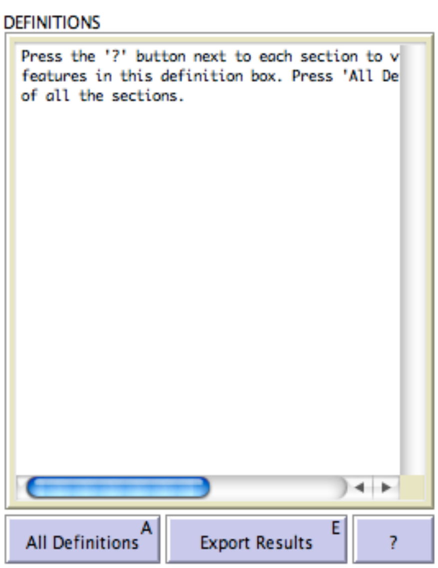
## 4 HELP BUTTONS




Pressing **HELP** buttons (**?**), located on the right side of each model interface section, allows you to see definitions of model features in the **DEFINITIONS** box (see below). Each model section can be queried in this way.

To see definitions of all model features without pressing each **?** button, press the **All Definitions** button located below the **DEFINITIONS** box. In addition, definitions are listed in ***APPENDIX B: MODEL DETAILS & DEFINITIONS*** (**page 56**) of this Manual.

You can also look for help by selecting **Help** in the NetLogo menu bar. The **Search** option can direct you to specific menu items or help topics. The **Look Up In Dictionary (F1)** option opens a web browser with the dictionary entry for the selected code. The **NetLogo User Manual** and **NetLogo Dictionary** links will open the manual and dictionary in a web browser. The **NetLogo Users Group** option will link you to the NetLogo Users Group, also in a web browser.




This is the **DEFINITIONS** box as it appears on the model interface. Feature definitions can be viewed by using the blue bar to scroll across the text content.

All definitions can be accessed by pressing **A** on the keyboard. This is the shortcut for the **All Definitions** button.

Button shortcuts are displayed in the upper-right corners of the buttons. **E** is the shortcut for the **Export Results** button, **S** is the shortcut for the **Setup** button, **D** is the shortcut for the **Defaults** button, etc.

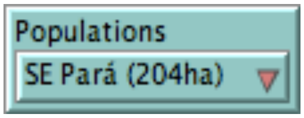
A button shortcut will appear **black** when enabled and **gray** when disabled. To enable shortcuts, click anywhere in the white background of the model interface.

Additional questions can be directed to the authors listed at the end of the Manual (**section 17**).

# 5 A BRIEF GUIDE

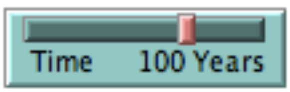
The following guide describes the most basic method for simulating a pre-defined big-leaf mahogany population.

### *Step 1. Designate Initial Population to Simulate*



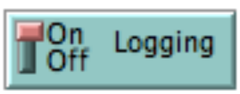

Select either a pre-defined example population or upload your own data using one of the ***USER DATA UPLOAD*** options (**section 9**).

### *Step 2. Set Simulation Time Limit*

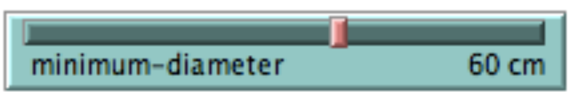



A simulation will end when the time limit is reached or when all the trees are harvested or die. Adjust the time limit by using your computer cursor to slide the red bar horizontally across the dark green slider. Movements to the right increase the parameter values while movements to the left decrease the parameter values.

### *Step 3. Set Logging Parameters*

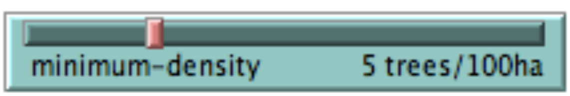



To simulate the population with a harvest regime, select logging 'On', otherwise select logging 'Off'. If logging:



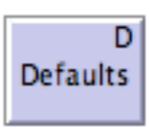

Set a minimum diameter cutting limit (default = 60 cm diameter)


Set a commercial tree retention rate (default = 20% commercial retention)



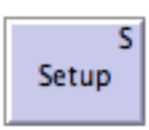

Set a minimum post-harvest commercial population density (default = 5 trees / 100 ha)


Set a cutting cycle length (default = 30 years)



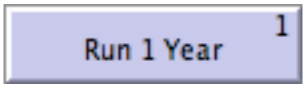

Default harvest parameters can be restored using the **Defaults** button in the upper left-hand corner of the model interface. This button also restores default model settings. Default conditions are reviewed below (**sections 6.2 & 7**).

### *Step 4. Setup Initial Population*




Establish the initial population on the landscape. The population will appear on the model interface in the 'landscape' (middle) field. The landscape population can be resized using the **Patch-Area** input and the **Resize** button (**section 6.1**).

### *Step 5. Begin Simulations*

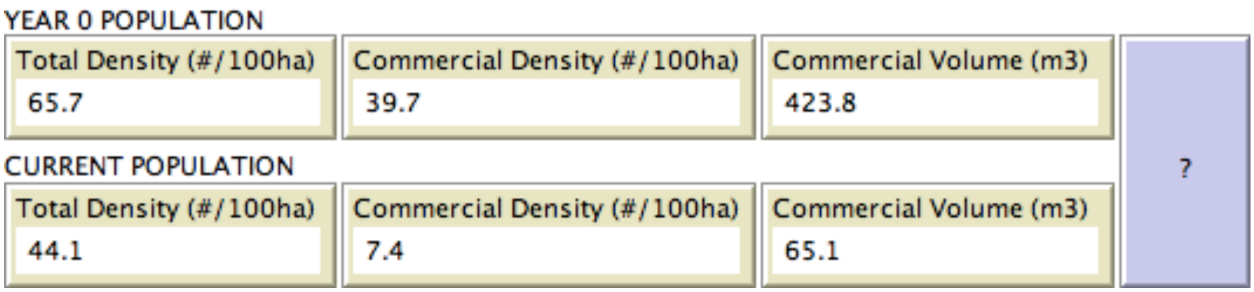



Run the simulation for a single year. This feature is useful when carefully monitoring a simulation or when troubleshooting.

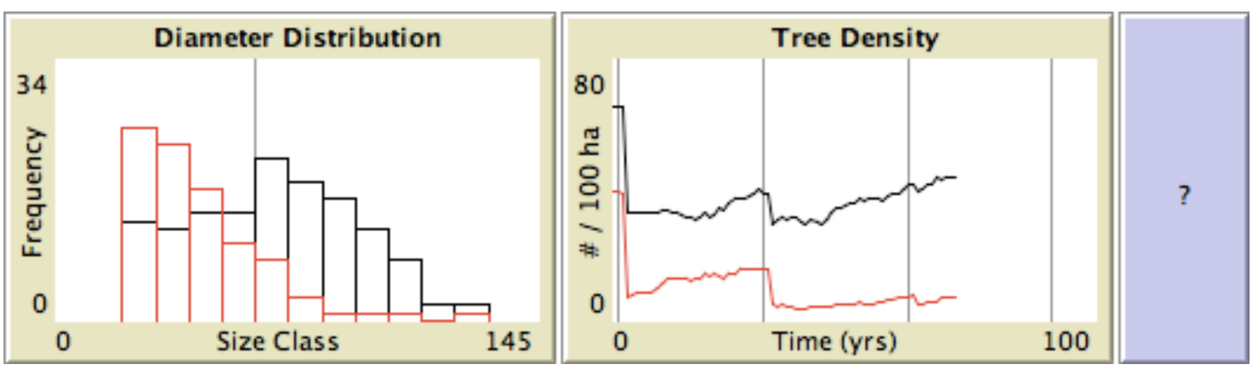

Run the simulation until the time limit is reached, or until all trees are harvested or die, if this occurs before reaching the time limit.

### *Step 6. Monitor Simulations*

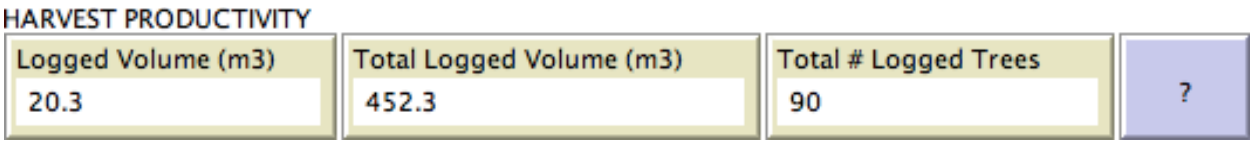
**Year 0 Population** and **Current Population** monitors report total tree density (trees ≥ 20 cm diameter / 100 ha), commercial-sized tree density (commercial trees / 100 ha), and commercial-sized tree volume ($m^3$) during **Year 0** and the **Current** simulation year.




**Current Population** plots show changes in tree size-class distribution and density (trees / 100 hectares) over time. These plots are updated each year according to simulation results. The **Diameter Distribution** plot shows the initial size-class distribution in **black** and the current year size-class distribution in **red**. The vertical **gray** line divides non-commercial and commercial trees. The **Tree Density** plot shows the density of all trees ≥ 20 cm diameter (trees / 100 hectares) in **black** and the density of commercial-sized trees in **red**. The vertical **gray** lines indicate the harvest years, that is, 1, 31, 61, and 91 years in the example shown.



**Harvest Productivity** monitors report the volume of trees logged in the most recent harvest as well as the number and volume of trees logged in all previous harvests. Monitors are updated after each logging event. **Logged Volume** reports the volume ($m^3$) of trees logged in the most recent harvest. **Total Logged Volume** reports the volume ($m^3$) of trees logged in all previous harvests. **Total # Logged Trees** reports the number of trees logged in all previous harvests.

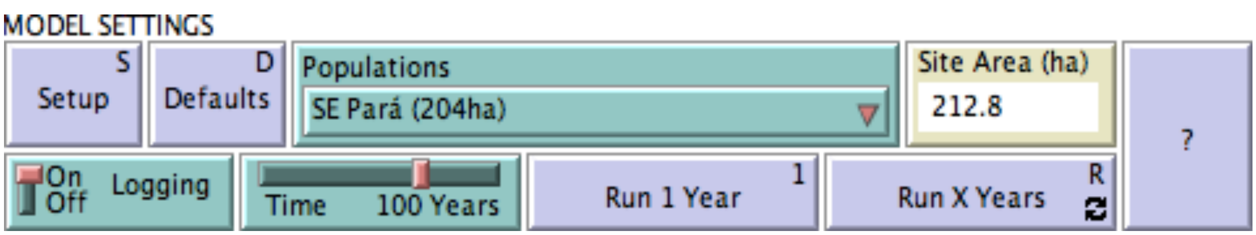



***Step 7. Export Simulation Results***


Export the simulation results to a text (.txt) file on your computer. Results describe initial and final populations and harvest productivity.

## 6 MODEL SETTINGS

The **MODEL SETTINGS** parameters determine: (1) which population is simulated during model runs; (2) whether logging is performed; and (3) how long the simulation is run. The **MODEL SETTINGS** buttons set up the initial population, re-set parameters to default conditions, and begin model simulations. The area (in hectares, or ha) of the field site is also displayed in this section.




### 6.1 Setup & Resize Initial Population

The **Setup** button establishes the initial population on the model landscape shown across the center of the model interface. The population displayed on the landscape is selected from the **Populations** menu, which lists three pre-defined example populations and three user-defined population upload options.

The example populations are based on mahogany population and spatial data from study sites in southeast Pará and Acre, Brazil. The user populations represent the three methods for uploading user data into the model. The six population options are summarized below. User populations are discussed in greater depth in ***USER DATA UPLOAD*** (section 9).

**EXAMPLE POPULATIONS**

| | |
|---|---|
| **SE Pará (204ha)** | 204-ha field site with 158 trees |
| **SE Pará (1035ha)** | 1035-ha field site with 745 trees |
| **Acre/West Amazon** | 685-ha field site with 81 trees |

**SE Pará (204ha)** and **SE Pará (1035ha)** present spatial diameter data for mahogany populations in southeast Pará, Brazil. The forest management and long-term research site, called Marajoara, is located 34 km northwest of Redenção. Marajoara was selectively logged for mahogany during 1992–1994. The population in 204 ha is from a 100% inventory for mahogany trees ≥ 20 cm diameter. The population in 1035 ha contains the 204-ha population but at lower sampling resolution, representing > 80% of trees ≥ 20 cm diameter in this larger forest area. Most of the trees presented here are logged stumps. For more details see Grogan *et al*. references (**section 16**).

**Acre/West Amazon** presents spatial diameter data for a mahogany population located 40 km south of Sena Madureira in the western Brazilian state of Acre. This data is from a 100% inventory in 685 ha for mahogany trees ≥ 20 cm diameter. At the time of inventory this was an unlogged population. The low landscape-scale density is typical of western Amazonian mahogany populations.

**USER POPULATIONS**

| | |
|---|---|
| **User Population (xyd)** | upload spatial diameter data from a spreadsheet |
| **User Population (shp)** | upload spatial diameter data from a shapefile |
| **User Population (csv)** | upload non-spatial diameter data from a spreadsheet |

The site is drawn in the 'landscape' (middle) field of the model interface. If the site is drawn too small for the available space, increase the value shown in **Patch-Area** and press the **Resize** button (upper-right on interface). If the site is drawn too large for the available space, decrease the value shown in **Patch-Area** and press the **Resize** button. Continue to make adjustments by increasing or decreasing the **Patch-Area** until you are satisfied with the size of your site on the interface. See **section 9.1 Step 4** for more details.

## 6.2 Setup & Run Simulations

The **Logging** and **Time** parameters determine how the model will simulate the initial population. The **Logging** switch determines whether the population is simulated with or without logging. Select 'On' to run simulations with logging. Select 'Off' to run simulations without logging.

The **Time** slider determines how long the simulation will run. The model will simulate the growth and harvest of the initial population until the time limit is reached or until all trees are harvested or die, whichever happens first. Population growth and harvests can be simulated up to 150 years. Changes to the simulation length can be made in 5-year increments.

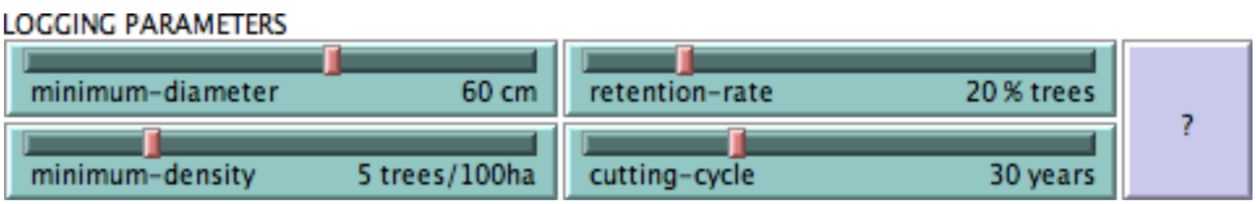
The **Run 1 Year** button runs the model for a single year. The **Run X Years** button runs the model until the time limit is reached or until all trees are harvested or die.

The **Defaults** button returns all variables to default conditions:

| | | | |
|---|---|---|---|
| **Populations** | SE Pará (204 ha) | **Logging** | On |
| **Patch-Area** | 2.75 pixels | **Time** | 100 years |

## 7 LOGGING PARAMETERS

The default harvest parameters are set according to current Brazilian forest management regulations for mahogany. These regulations mandate a minimum diameter cutting limit of ≥ 60 cm, the retention of ≥ 20% of commercial-sized trees, the prohibition of logging in areas with population densities ≤ 0.05 trees ha$^{-1}$ (5 commercial trees / 100 ha), and a cutting cycle of 25–30 years.




Harvest parameters can be changed according to user preference. Each parameter can be reset using the computer cursor to move the red bar across the green slider. Movements to the right increase the parameter values while movements to the left decrease the parameter values. The minimum value, maximum value, and value increment are listed for each parameter below:

| | |
|---|---|
| **Minimum Diameter** | 0 – 100 cm; 5-cm increments |
| **Retention Rate** | 0 – 100% retention; 5% retention increments |
| **Minimum Density** | 0 – 20 trees / 100 ha; 1 tree / 100 ha increments |
| **Cutting Cycle** | 0 – 100 years; 5-year increments |

Pressing the **Defaults** button will return the logging parameters to default conditions.

| | | | |
|---|---|---|---|
| **Minimum Diameter** | 60 cm | **Retention Rate** | 20% trees |
| **Minimum Density** | 5 trees / 100 ha | **Cutting Cycle** | 30 years |

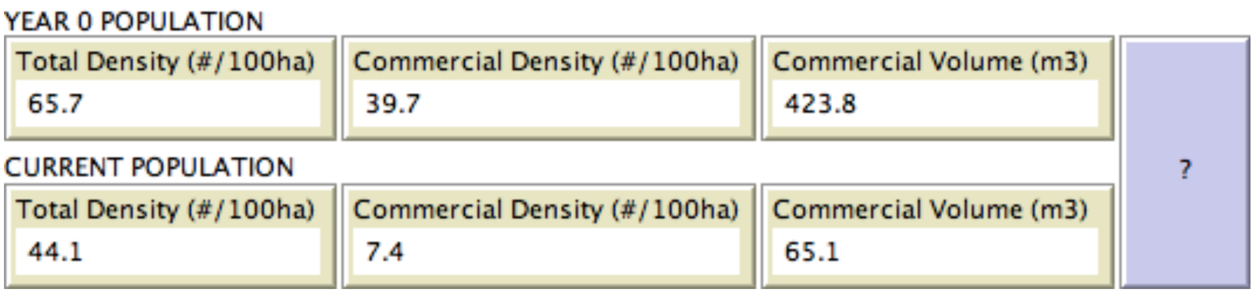
If you do not want to simulate logging, turn logging off using the **Logging** switch discussed above.

# 8 SIMULATION RESULTS

The model interface provides information to allow users to observe simulations as they progress.

## 8.1 Population Monitors

The **YEAR 0 POPULATION** and **CURRENT POPULATION** monitors report total tree density, commercial tree density, and commercial tree volume during year 0 and the current simulation year, respectively. **YEAR 0 POPULATION** monitors are static, while **CURRENT POPULATION** monitors are updated each year according to simulation results.




**Density** monitors report tree density as the number of trees per 100 hectares. Density can be converted to abundance using the following equation:

$$Abundance = Density * (\text{Site } Area / 100)$$

where density (trees / 100 ha) is either total or commercial density and area (ha) is the **Site Area**, as reported in the upper-right portion of the **MODEL SETTINGS** section of the model interface.

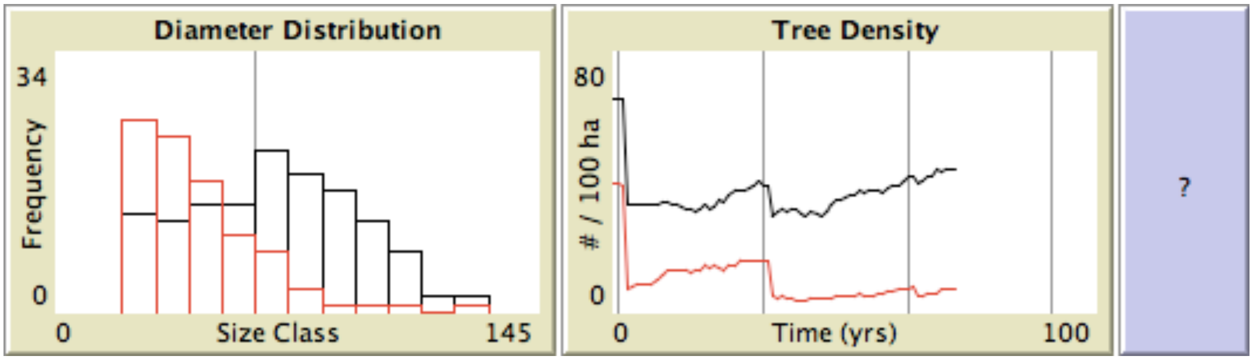
**Volume** monitors report volume in cubic meters ($m^3$). Volume is calculated from the diameter of each tree according to the equation:

$$Volume\ (m^3) = -5.297672 + (0.1263387 * Diameter)$$

where tree diameters (cm) are measured 1.3 m above the forest floor or at least 30 cm above the reach of the tallest buttress (Kometter 2011).

## 8.2 Population Plots

The **CURRENT POPULATION** plots show changes in tree size-class distribution and population density over time. These plots are updated each year according to simulation results.

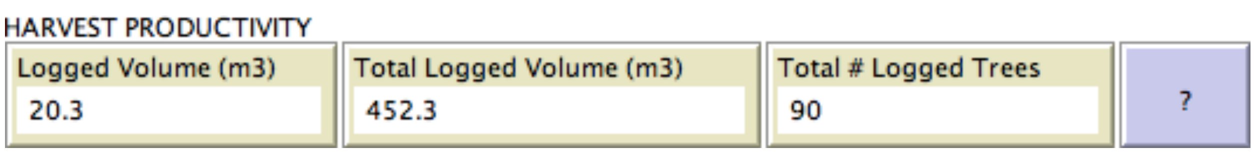



The **Diameter Distribution** plot shows the initial size-class distribution in **black**. This distribution is static. The current year size-class distribution is shown in **red**. This distribution updates each year according to simulation results. The diameter size classes are defined by 10-cm intervals and only trees ≥ 20 cm diameter are plotted. The vertical **gray** line divides commercial and non-commercial trees as determined by the minimum diameter cutting limit.

The **Tree Density** plot shows the density of trees over time (trees / 100 ha). The **black** line tracks the density of all trees ≥ 20 cm diameter. The **red** line tracks the density of commercial-sized trees. The vertical **gray** lines indicate the harvest years, that is, 1, 31, 61, and 91 years in the example shown.

## 8.3 Harvest Productivity Monitors

**HARVEST PRODUCTIVITY** monitors report the volume of trees logged in the most recent harvest as well as the number and volume of trees logged in all previous harvests. Monitors are updated after each logging event.




**Logged Volume** reports the volume ($m^3$) of trees logged in the most recent harvest.
**Total Logged Volume** reports the volume ($m^3$) of trees logged in all previous harvests.
**Total # Logged Trees** reports the number of trees logged in all previous harvests.

# 9 USER DATA UPLOAD

You can simulate population growth and harvest outcomes of a mahogany population at your own site using the **DATA UPLOAD** portion of the model interface. At minimum you will need diameter data for the trees within your site.

If you have both spatial distribution (mapping) and tree diameter data, you can upload the data from a spreadsheet or, if available, from a GIS shapefile. Refer below to ***Spatial Diameter Data: User Spreadsheet*** and ***Spatial Diameter Data: User Shapefile*** (**sections 9.1 & 9.2**), respectively, for instructions.

If you only have diameter data, you can upload the data from a spreadsheet, but you will need to know or estimate the dimensions or approximate area of your site. Refer to ***Non-Spatial Diameter Data: User Spreadsheet*** (**section 9.3**) below.

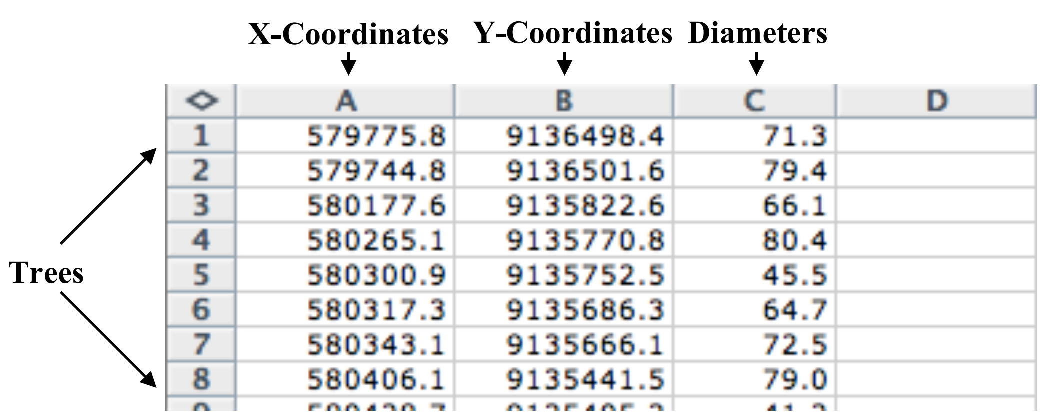
## 9.1 Spatial Diameter Data: User Spreadsheet

This section describes the procedures necessary to upload diameter data with spatial location information from a user spreadsheet. The spatial diameter data must be formatted according to the instructions below for the model to accept the user data.

***Step 1. Data Structure and Format***

The first step is to structure your data so the computer can read the information into the model. Create an Excel (.xls)-type spreadsheet to organize the data into three columns: X-coordinates, Y-coordinates, and tree diameters. The columns *must* be listed in this order for your data to be read into the model.

*Column A* should contain the X-coordinates (longitude) of each tree. *Column B* should contain the Y-coordinates (latitude) of each tree. *Column C* should contain the diameter in centimeters of each tree. DO NOT GIVE THE COLUMNS HEADERS. The head of your file should look like the example file shown below.




| | A | B | C | D |
|---|---|---|---|---|
| 1 | 579775.8 | 9136498.4 | 71.3 | |
| 2 | 579744.8 | 9136501.6 | 79.4 | |
| 3 | 580177.6 | 9135822.6 | 66.1 | |
| 4 | 580265.1 | 9135770.8 | 80.4 | |
| 5 | 580300.9 | 9135752.5 | 45.5 | |
| 6 | 580317.3 | 9135686.3 | 64.7 | |
| 7 | 580343.1 | 9135666.1 | 72.5 | |
| 8 | 580406.1 | 9135441.5 | 79.0 | |

The XY coordinates (longitude/latitude) *must* be measured in either meters or decimal degrees. In the example above, coordinates are given in UTM (Universal Transverse Mercator) geographic coordinate units taken from a standard GPS unit. Alternatively, coordinates could be given in user-assigned meter units derived from a field-based inventory.

Coordinates *cannot* be given in degrees, minutes, and seconds. Coordinates measured in this format can be converted here: http://www.fcc.gov/mb/audio/bickel/DDDMMSS-decimal.html.

Diameters *must* be measured in centimeters (cm). Tree diameter measurements should be taken at 1.3 m above the forest floor or at least 30 cm above the reach of the tallest buttress.

### *Step 2. Save As Text File*

The model software cannot read data from Excel (.xls) files so the data must be saved as a text (.txt) file. In Excel or a similar spreadsheet program, choose *File > Save As* and select *Text (tab delimited)* from the *Save As* options. Include the *.txt* extension in the file name. The head of the new text file should look like this, WITHOUT COLUMN HEADERS:

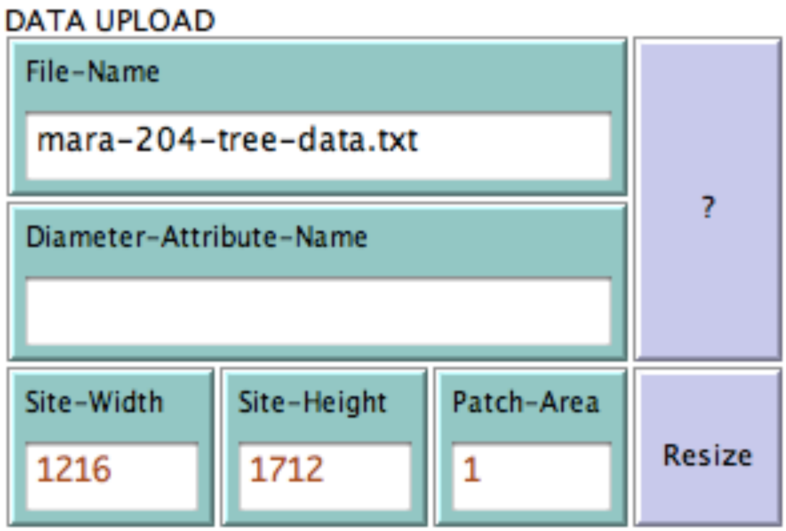
**Trees**

| **X-Coordinates** | **Y-Coordinates** | **Diameters** |
|---|---|---|
| 579775.8 | 9136498.4 | 71.3 |
| 579744.8 | 9136501.6 | 79.4 |
| 580177.6 | 9135822.6 | 66.1 |
| 580265.1 | 9135770.8 | 80.4 |
| 580300.9 | 9135752.5 | 45.5 |
| 580317.3 | 9135686.3 | 64.7 |
| 580343.1 | 9135666.1 | 72.5 |
| 580406.1 | 9135441.5 | 79 |
| 580428.7 | 9135405.3 | 41.2 |

Place the new text file in the *Model > User* folder. Remember the name of the new text file.

### *Step 3. NetLogo File Parameters*

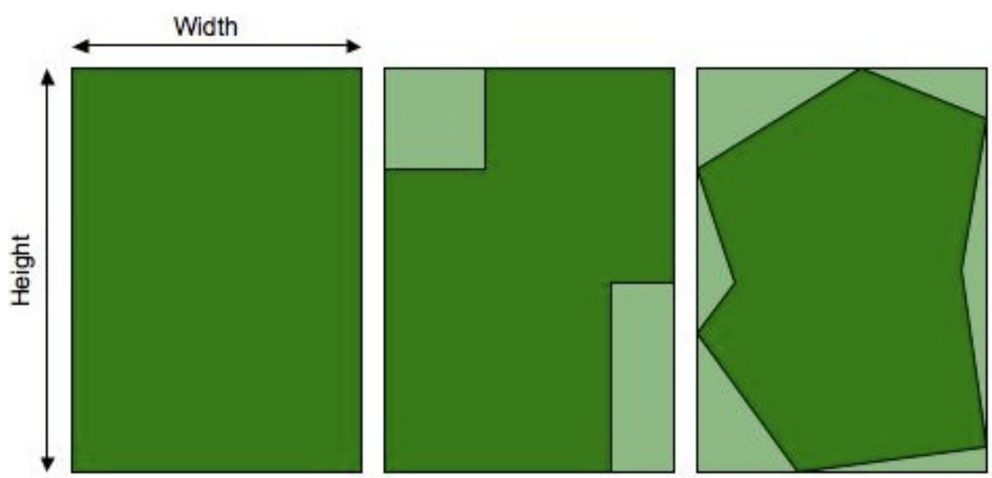
The final steps towards uploading your data into the model are completed in the **DATA UPLOAD** portion of the model interface. These parameters specify the name of the user data file, the dimensions of the user field site, and the resolution of the resulting landscape.




Type the name of the text file from Step 2 containing spatial diameter data (located in the *User* folder) into the **File-Name** input box. Be sure to include the '.txt' file extension when typing the name.

Leave the **Diameter-Attribute-Name** input blank. This input is only necessary for data uploaded from a user shapefile (**section 9.2**). Input here will interfere with the present upload.

Type the width (X, in meters) of your site into the **Site-Width** input box and the height (Y, in meters) of your site into the **Site-Height** input box. If your site is not rectangular, estimate the width and height of the smallest bounding rectangle (examples shown below). Again, the width and height of your site must be in meters (m).




Type the value 1.00 into the **Patch-Area** input box. **Patch-Area** determines the size of landscape patches in pixels and therefore determines the size of the landscape. A **Patch-Area** of 1.00 is purposefully small and should draw a landscape contained by the available space on the model interface.

### *Step 4. Resize Site Drawing*

After **File-Name**, **Site-Width**, **Site-Height**, and **Patch-Area** have been specified, press the **Setup** button under **MODEL SETTINGS** to draw your site on the model interface. If the site dimensions are incorrect, ensure that the file is formatted correctly (columns: X-coordinate, Y-coordinate, diameter). If you receive an error message, refer to ***Error Messages & Trouble Shooting*** (**section 9.4**) below.

The site should be drawn using a **Patch-Area** of 1.00 pixel but a larger or smaller **Patch-Area** may be preferred depending on the dimensions of your site. If the site is drawn too small for the available space, increase the **Patch-Area** by entering 2.00 and press the **Resize** button. If the site is drawn too large for the available space, decrease the **Patch-Area** by entering 0.50 and press the **Resize** button. Continue to make adjustments by increasing or decreasing the **Patch-Area** until you are satisfied with the size of your site projected onto the model interface.

### *Step 5. Trouble Shooting*

If you require quick assistance, press the **?** button for a summary of the **DATA UPLOAD** features or refer to this manual. See ***Error Messages & Trouble Shooting*** (**section 9.4**) below for a discussion of error messages you may encounter when uploading your data into the model.

## 9.2 Spatial Diameter Data: User Shapefile

This section describes the procedures necessary to upload your data from a GIS shapefile. A shapefile is a file type produced by GIS software to store location and attribute data. This user data upload feature will not support any other geospatial file format.

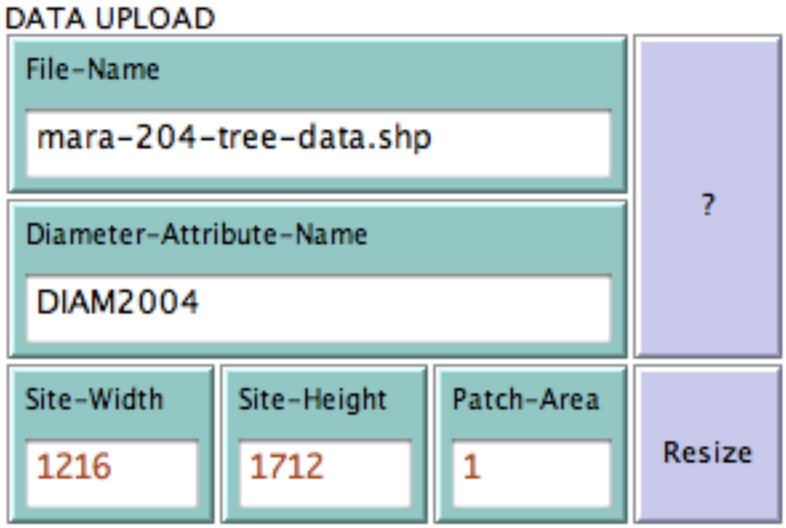
### *Step 1. Place Shapefile in User Folder*

Place the shapefile containing spatial diameter data of your tree population in the *Model > User* folder. Place the dbf file (.dbf) associated with the shapefile here as well (the .prj, .sbn, .sbx, .shx, and .xml files are not necessary). Remember the name of the overarching shapefile (.shp).

### *Step 2. NetLogo File Parameters*

Parameters in the **DATA UPLOAD** portion of the model interface shown on the next page specify the name of the user data file, the name of the diameter attribute, the dimensions of the field site, and the resolution of the landscape.

Type the name of the shapefile from Step 1 containing spatial diameter data (located in the *User* folder) in the **File-Name** input box. Include the '.shp' file extension when typing the name.
Type the name of the attribute (data column header) in the shapefile containing the diameter data in the **Diameter-Attribute-Name** input box. The diameters listed in the shapefile *must* be measured in centimeters (cm). Tree diameter measurements should be taken at 1.3 m above the forest floor or at least 30 cm above the reach of the tallest buttress.




Type the width (X, in meters) of your site into the **Site-Width** input box and the height (Y, in meters) of your site into the **Site-Height** input box. If your site is not rectangular, estimate the width and height of the smallest bounding rectangle (see examples, p. 20). Again, the width and height of your site must be in meters (m).

Type the value 1.00 into the **Patch-Area** input box. **Patch-Area** determines the size of landscape patches in pixels and therefore determines the size of the landscape. A **Patch-Area** of 1.00 is purposefully small and should draw a landscape contained by the available space on the model interface.

***Step 3. Resize Site Drawing***

After **File-Name**, **Diameter-Attribute-Name, Site-Width**, **Site-Height**, and **Patch-Area** have been specified, press the **Setup** button under **MODEL SETTINGS** to draw your site on the model interface. The site should be drawn using a **Patch-Area** of 1.00 pixel but a larger or smaller **Patch-Area** may be preferred depending on the dimensions of your site.

If the site is drawn too small for the available space, increase the **Patch-Area** by entering 2.00 and press the **Resize** button. If the site is drawn too large for the available space, decrease the **Patch-Area** by entering 0.50 and press the **Resize** button. Continue to make adjustments by increasing or decreasing the **Patch-Area** until you are satisfied with the size of your site on the model interface.

***Step 4. Trouble Shooting***

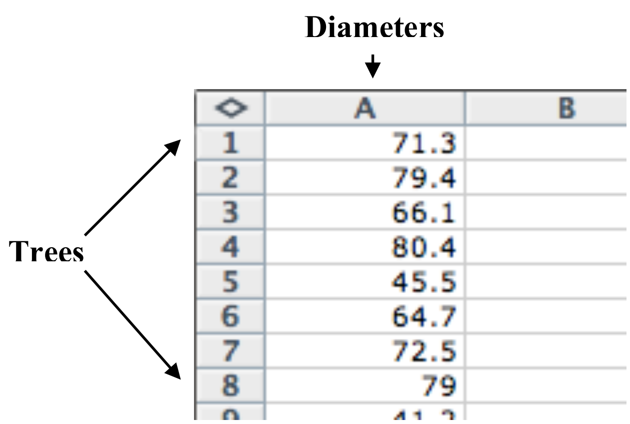
If you require quick assistance, press the **?** button for a summary of the **DATA UPLOAD** features or refer to this manual. See ***Error Messages & Trouble Shooting*** (**section 9.4**) below for a discussion of error messages you may encounter when uploading your data into the model.

## 9.3 Non-Spatial Diameter Data: User Spreadsheet

This section describes the procedures necessary to upload diameter data without spatial location information into the model interface. Although spatial diameter data is not required for this data upload feature, you must know or estimate the physical dimensions or area (ha) of your field site.

***Step 1. Data Structure and Format***

The first step is to structure your data so the computer can read the information into the model. Create a spreadsheet to organize the data into a single column: tree diameter (cm). DO NOT GIVE THE COLUMN A HEADER. The head of your file should look like this:




Diameters *must* be measured in centimeters (cm). Tree diameter measurements should be taken at 1.3 m above the forest floor or at least 30 cm above the reach of the tallest buttress.

***Step 2. Save As CSV File***

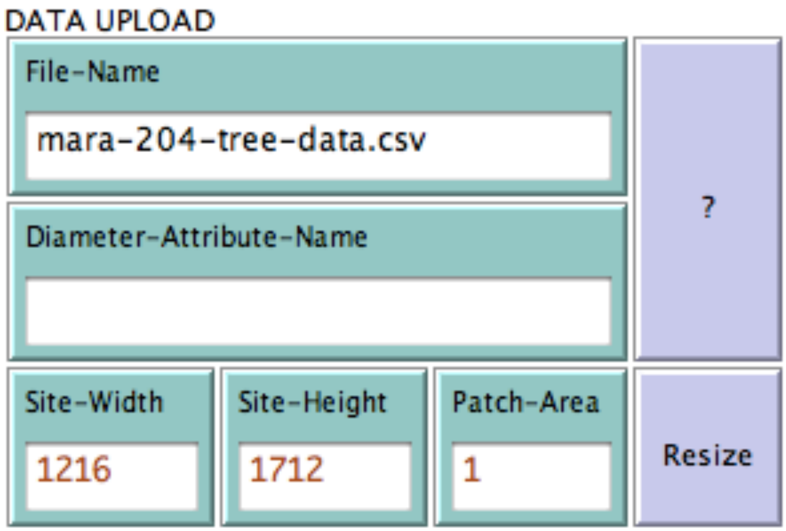
The model software cannot read data from Excel (.xls) or similar files; the data must be saved as a comma separated value (.csv) file. Choose *File* > *Save As* and select *CSV (comma delimited)* from the *Save As* options. INCLUDE THE '.CSV' EXTENSION IN THE FILE NAME.

Place the new .csv file in the *Model* > *User* folder. Remember the name of the .csv file.

***Step 3. NetLogo File Parameters***

The final steps towards uploading your data into the model are completed in the **DATA UPLOAD** portion of the model interface. These parameters specify the name of the user data file, the dimensions of the user field site, and the resolution of the resulting landscape.

Type the name of the .csv file from Step 2 containing diameter data (located in the *User* folder) into the **File-Name** input box. Be sure to include the '.csv' file extension when typing the name.




Leave the **Diameter-Attribute-Name** input blank. This input is only necessary for data uploaded from a user shapefile (**section 9.2**). Input here will interfere with the present upload.

Type the width (X, in meters) of your site into the **Site-Width** input box and the height (Y, in meters) of your site into the **Site-Height** input box. If your site is not rectangular, estimate the width and height of the smallest bounding rectangle (see examples, p. 20). Again, the width and height of your site must be in meters (m).

Type the value 1.00 into the **Patch-Area** input box. **Patch-Area** determines the size of landscape patches in pixels and therefore determines the size of the landscape. A **Patch-Area** of 1.00 is purposefully small and should draw a landscape contained by the available space on the model interface.

***Step 4. Resize Site Drawing***

After **File-Name**, **Site-Width**, **Site-Height**, and **Patch-Area** have been specified, press the **Setup** button under **MODEL SETTINGS** to draw your site on the model interface. The site should be drawn using a **Patch-Area** of 1.00 pixel but a larger or smaller **Patch-Area** may be preferred depending on the dimensions of your site.

If the site is drawn too small for the available space, increase the **Patch-Area** by entering 2.00 and press the **Resize** button. If the site is drawn too large for the available space, decrease the **Patch-Area** by entering 0.50 and press the **Resize** button. Continue to make adjustments by increasing or decreasing the **Patch-Area** until you are satisfied with the size of your site on the model interface.

***Step 5. Trouble Shooting***

If you require quick assistance, press the **?** button for a summary of the **DATA UPLOAD** features or refer to this manual. See ***Error Messages & Trouble Shooting*** (**section 9.4**) below for a discussion of error messages you may encounter when uploading your data into the model.

## 9.4 Error Messages & Trouble Shooting

If an error occurs while uploading your data, the model will stop the uploading process and present a message explaining the cause of the error. The following is a list of potential error messages and possible solutions.

**A 'Population' must be selected.** You selected the blank population option. Please select an actual population to simulate.

**An 'Example Population' must be selected.** You selected the **Example Population** heading. Please select an actual example population to simulate.

**A 'User Population' must be selected.** You selected the **User Population** heading. Please select an actual user population to simulate.

**A 'File-Name' must be specified.** You selected a **User Population** but did not specify a user data file. Please provide the name of the user data file or choose an example population.

**'File-Name' must be a .txt file.** You selected the **User Population (xyd)** option, which requires a user text file, but the file specified in **File-Name** does not have a .txt extension. Please ensure the file is a text file and has the text file extension (.txt).

**'File-Name' must be a .shp file.** You selected the **User Population (shp)** option, which requires a user shapefile, but the file specified in **File-Name** does not have a .shp extension. Please ensure the file is a shapefile and has the shapefile extension (.shp).

**A 'Diameter-Attribute-Name' must be specified.** You selected the **User Population (shp)** option, which requires a **Diameter-Attribute-Name**, but the **Diameter-Attribute-Name** field is empty. Please provide the name of the shapefile diameter attribute in this field.

**'File-Name' must be a .csv file.** You selected the **User Population (csv)** option, which requires a user csv file, but the file specified in **File-Name** does not have a .csv extension. Please ensure the file is a csv file and has the csv file extension (.csv).

**'Site-Width' must be a positive non-zero number.** You provided a non-zero (negative or zero) site width. Please provide a positive site width measured in meters (m).

**'Site-Height' must be a positive non-zero number.** You provided a non-zero (negative or zero) site height. Please provide a positive site height measured in meters (m).

**'Patch-Area' must be a positive non-zero number.** You provided a non-zero (negative or zero) patch area. Please provide a positive patch area measured in meters (m).

**The site cannot be set up. Please review the file formatting / placement guidelines.** You most likely received this error because the data file is formatted incorrectly or is not located in the *Model* > *User* folder. The data file should be placed in the *User* folder and should not have

any headers, commas, spaces, or other symbols. Review this manual to ensure proper formatting.

## 9.5 User Data Upload Examples

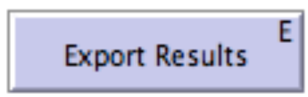
There are example user files in the *Model > User* folder to help illustrate the user data upload process. The folder contains the files necessary to set up the **SE Pará (204ha)** population using each of the three user data upload methodologies.

The files and inputs required for each methodology are listed below. If you have any questions about formatting, look to these files as templates. If you have questions about the inputs, look to the information below and the **DATA UPLOAD** figures presented above (**sections 9.1, 9.2 & 9.3**).

| Data Upload Type | File-Name | DIAM-Attribute-Name | Site-Width | Site-Height | Patch-Area |
|---|---|---|---|---|---|
| Spatial: TXT file | mara-204-tree-data.txt | | 1216.1 | 1712.4 | 1.0 |
| Spatial: SHP file | mara-204-tree-data.shp* | DIAM2004 | 1216.1 | 1712.4 | 1.0 |
| Non-Spatial: CSV file | mara-204-tree-data.csv | | 1216.1 | 1712.4 | 1.0 |

*The mara-204-tree-data.dbf file in the *Model > User* folder is associated with this shapefile and is necessary for data upload using this method.

# 10 EXPORT SIMULATION RESULTS




The monitors, plots, and landscape features provide a means for observing simulation results in real time, but these results are not stored in memory or elegantly summarized for the user. Simulation end results can be permanently stored and easily reviewed by pressing the **Export Results** button. The resulting file summarizes a given simulation by showing the model settings, harvest parameters, and initial population, final population, and harvest statistics.

Simulation results must be saved as a text (.txt) file. These files can be named and placed anywhere on your computer. It may be useful to name your file based on the simulated parameters. For example, *Marajoara-60cm-20rr-5md-30yr-1* indicates the population simulated, while *cm*, *rr*, *md*, and *yr* indicate the simulated minimum diameter cutting limit, retention rate, minimum density, and cutting cycle, respectively, and *1* indicates the simulation number.

**Results** text files can be opened with *Notepad* on Windows and *TextEdit* on Mac OS X. If you are missing either of these programs (they come pre-installed on your computer), free alternatives are available online. For Windows users, *Another Notepad* is a simple and free text editor: http://www.pc-shareware.com/anotepad.htm. For Mac users, *Plain Text Editor* is also a simple and free text editor: http://www.macupdate.com/app/mac/8724/plain-text-editor.

**SIMULATION RESULTS**, the head of the **Results** file, summarizes the model settings used in the completed simulation. This section lists: (1) the name of the field site (the data file name, if

running a user population); (2) the area of the field site in hectares; (3) whether logging was turned on or off; and (4) the number of harvest cycles, the simulation time limit in years, and the actual time run in years.

The second section of the **Results** file reminds the user that additional simulations are necessary to validate the results of a single simulation. This can be achieved by repeating the same single-run simulation or by running a BehaviorSpace experiment as described in **section 11**.

The lines following these reminders define *Total Abundance/Density* and *Commercial Abundance/Density* as referred to in the **Results** file statistics. In all cases, *Total Abundance/Density* refers to trees ≥ 20 cm diameter. *Commercial Abundance/Density* refers to trees ≥ the minimum diameter cutting limit designated on the model interface.

The next section, **LOGGING PARAMETERS**, only appears if logging was turned on during the simulation and reports the logging parameter values used during the simulation. If the logging parameters are changed mid-simulation, only the end parameter values will be displayed.

**YEAR 0 STATISTICS** and **YEAR XXX STATISTICS** report the total density, commercial density, and commercial volume of the population in the initial and final years of the simulation. The year value in the **YEAR XXX STATISTICS** heading will be the final year of simulation, that is, a simulation lasting 100 years will read **YEAR 100 STATISTICS**.

The **HARVEST STATISTICS** section is only displayed if logging is turned on during the simulation. This section summarizes the number of harvests, number of trees logged, and volume of trees logged during the simulation runtime. The section also summarizes the results of each harvest by displaying the year and productivity of successive harvest events.

The **PRE/POST HARVEST ABUNDANCE & VOLUME** section summarizes the number and volume of commercial trees before/after each harvest if logging is turned on during simulations.

Finally, the **SIZE DISTRIBUTION (YEAR XXX)** section summarizes the size distribution of trees ≥ 20 cm diameter in the final year of simulation. The largest tree is always contained within the second largest size class, that is, the final size class will always contain 0 trees. The number of size classes changes based on the size distribution of trees in the final year but the size class increment is always 10 cm diameter.

## 11 SIMULATION EXPERIMENTS: BehaviorSpace

The NetLogo BehaviorSpace tool allows users to easily run repeat simulations of the Big-Leaf Mahogany Growth & Yield Model using either constant or systematically varied harvest parameter settings. The BehaviorSpace tool thus enables users to examine the outcomes of multiple harvest regimes with statistical confidence (repeat simulations) and methodological ease (automated process). Results from these simulations are then tabulated into a spreadsheet for analysis.

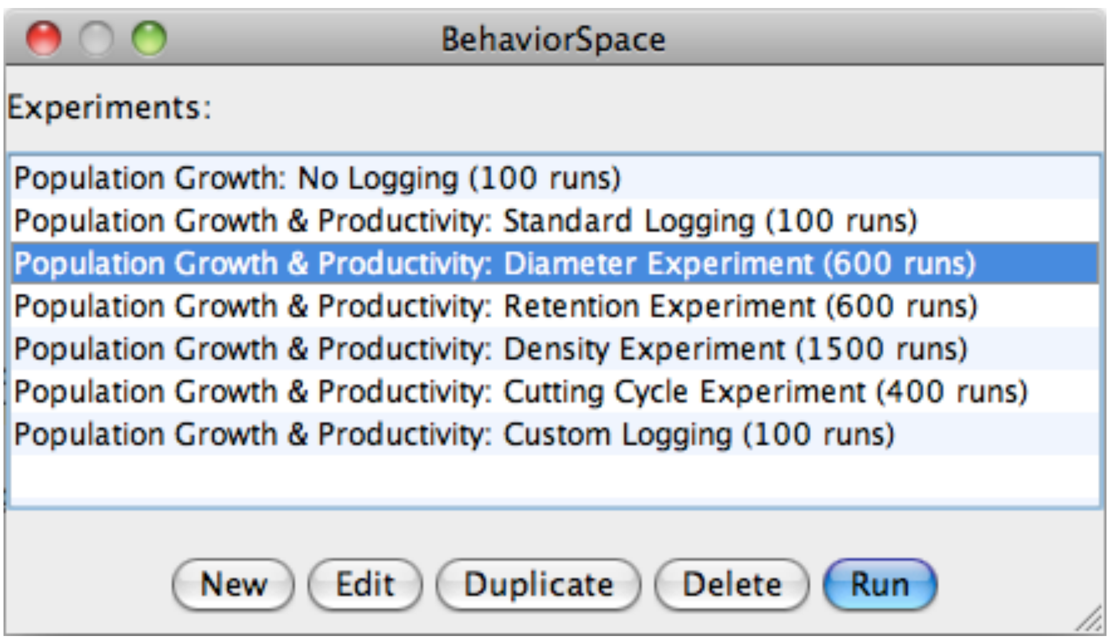
The following section explains how to run, modify, and analyze the seven built-in BehaviorSpace experiments.

### *Step 1. Define Model Parameters*

BehaviorSpace experiments will systematically vary the harvest parameters but you must define the other model settings before running an experiment. Define **Populations**, **Logging**, and **Time** on the model interface according to the directions above (**section 6.2**). If you intend to simulate one or more harvest regimes, be sure that the **Logging** switch is turned on.

### *Step 2. Open BehaviorSpace*

Open the BehaviorSpace tool by selecting **Tools > BehaviorSpace** in the NetLogo menu. The **BehaviorSpace** window will open in the center of your screen:




Seven built-in experiments are listed in this window. Resize the window to view the full experiment names by grabbing the triangle in the bottom-right corner. The function of each experiment is summarized below. The buttons in the **BehaviorSpace** window behave as follows:

| | |
|---|---|
| **New** | creates a new BehaviorSpace experiment |
| **Edit** | opens the selected BehaviorSpace experiment for editing |
| **Duplicate** | duplicates the selected BehaviorSpace experiment |
| **Delete** | deletes the selected BehaviorSpace experiment |
| **Run** | runs the selected BehaviorSpace experiment |

Before running an experiment, you should select the **Edit** option and familiarize yourself with the experiment's settings. The modification of these settings and the creation of new experiments are discussed more below (**section 12.2**).

### *Step 3. Choose a BehaviorSpace Experiment*

Choose a baseline BehaviorSpace experiment to match your experimental goals:

The **Population Growth: No Logging** experiment simulates the initial population without logging in order to examine the natural projection of the population.

The **Population Growth & Productivity: Standard Logging** experiment simulates the initial population under current (default) harvest standards in order to examine population recovery after logging following these legal guidelines.

The four **Population Growth & Productivity: Harvest Parameter** experiments examine the effect of each harvest parameter on population growth and harvest productivity by varying a single harvest parameter and keeping the other parameters constant.

The final **Population Growth & Productivity: Custom Logging** experiment provides a place for the user to define a single custom harvest regime to simulate the recovery and productivity of the initial population under these guidelines.

### *Step 4. Examine & Modify a BehaviorSpace Experiment*

Select the chosen baseline experiment in the **BehaviorSpace** window by pressing the name of the experiment. The name should now be highlighted in blue. Press **Edit** to edit the details of the experiment. The **Experiment** window, shown on the next page, will open in the center of your screen.

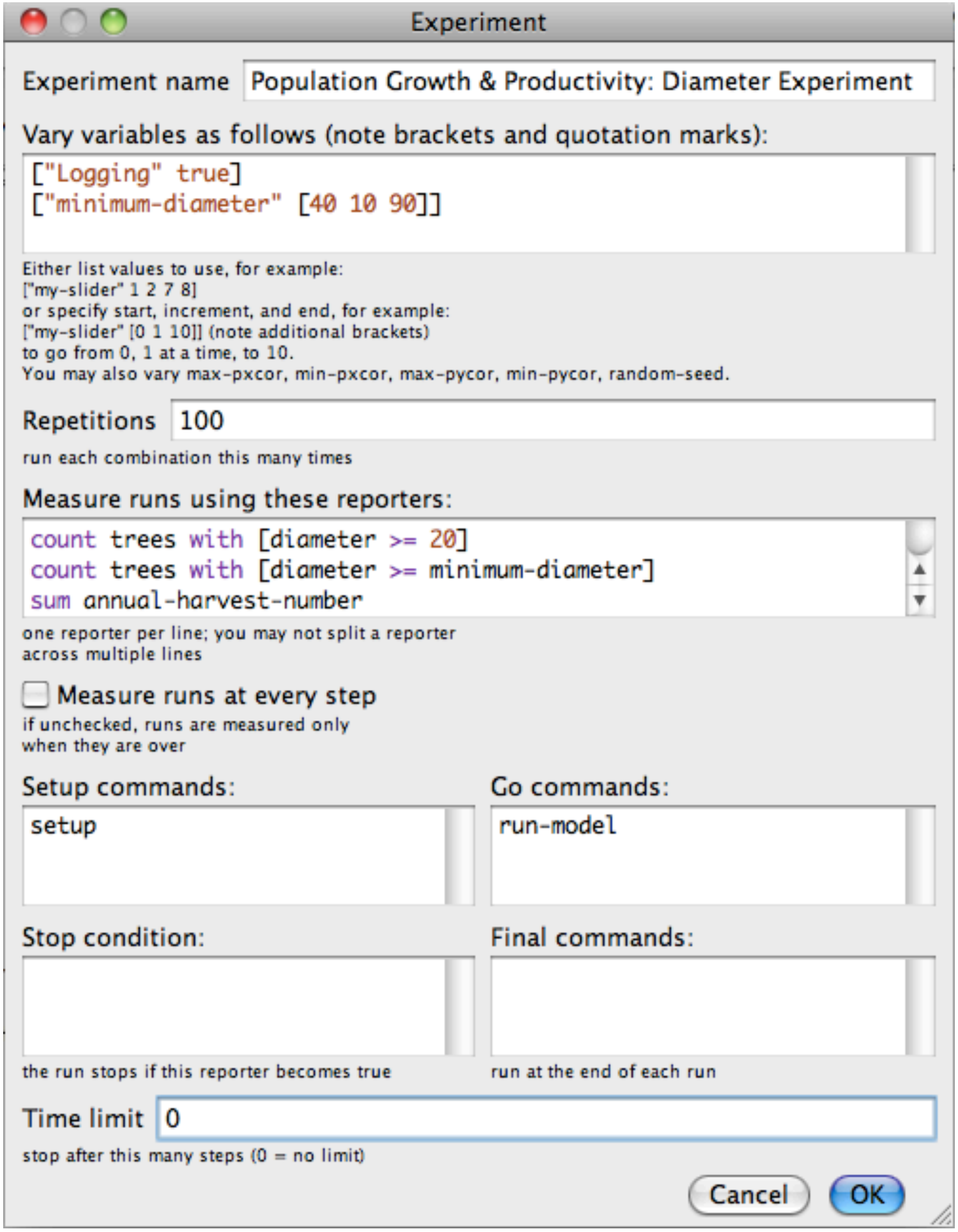
Resize the window as needed by grabbing the triangle in the bottom-right corner. The window displayed on the next page describes the **Population Growth & Productivity: Diameter Experiment**, as listed in the **Experiment name** field at the top of the window.

### *Experiment Variables*

The second field lists the **variables** to be examined during the BehaviorSpace simulation. In this experiment, logging is turned permanently on (*["logging" true]*) and the **minimum-diameter** is varied from 40 cm to 90 cm by increments of 10 cm (i.e., 40, 50, 60, 70, 80, 90 cm). All other harvest parameters and model settings will remain constant based on the current interface settings.

The **Vary variables** section has a similar structure in each experiment. **Population Growth: No Logging** is the only experiment with logging turned off because it is designed to monitor populations under natural conditions. **Population Growth & Productivity: Standard Logging**,

unlike the other experiments, permanently sets the four harvest parameters because it is designed to monitor populations under current legal management practices for mahogany in Brazil.




The other four **Population Growth & Productivity** experiments (**Diameter**, **Retention**, **Density**, **Cutting Cycle**) vary each harvest parameter according to the syntax described above: [*"harvest-parameter"* [*start increment end*]]. To examine a different range or resolution of parameter values, change the *start*, *increment*, and *end* values according to preference.

Alternatively, values to be tested can be listed using the following syntax: [*"harvest-parameter" value value value ...*]. For example, [*"minimum-diameter" 50 55 60 75 80*] would simulate the non-incremental minimum diameters of 50, 55, 60, 75, and 80 cm. MAKE SURE YOU USE THE BRACKETS EXACTLY AS SPECIFIED.

The **Repetitions** field specifies the number of simulations performed for each harvest parameter value. The **Population Growth & Productivity: Diameter Experiment** simulates six minimum diameter values (40, 50, 60, 70, 80 and 90 cm), each 100 times, for a total of 600 simulations. Type a new number into the **Repetitions** field to increase or decrease the simulation sample size.

***Experiment Reporters***

The **Measure runs using these reporters** field designates the reporters, or measurements, used to evaluate the simulated population. The reporters for the **Diameter Experiment** are repeated in all other experiments (except **Population Growth: No Logging** which does not require harvest reporters) as measures of population growth and harvest productivity:

| | |
|---|---|
| *count trees* | total tree abundance |
| *count trees with [diameter >= small-diam]* | abundance of trees ≥ 20 cm diameter |
| *count trees with [diameter >= minimum-diameter]* | abundance of commercial-sized trees |
| *sum annual-harvest-number* | summed number of logged trees |
| *sum annual-harvest-volume* | summed volume of logged trees |
| *annual-harvest-number* | number of trees logged in each harvest |
| *annual-harvest-volume* | volume of trees logged in each harvest |
| *pre-post-cut-number* | number of commercial trees before/after each harvest |
| *pre-post-cut-volume* | volume of commercial trees before/after each harvest |

If you would like to remove a reporter from this list, simply delete it from the box. If you would like to add or modify a reporter, refer to the sections below (**sections 12.1 & 12.2**). Note: a method for reporting harvest number/volume statistics in individual columns is detailed in **section 12.2**.

The reporters will be measured every year (time step) if the **Measure runs at every step** option is selected. This would generate an unnecessary amount of data so the default setting leaves this option unchecked. If you would like to track *every* year of *every* simulation, select this option.

***Experiment Run Settings***

The **Setup commands** and **Go commands** fields correspond to the commands in the model procedure responsible for setting and running the model. DO NOT CHANGE THESE FIELDS.

The **Stop condition** and **Time limit** fields are left purposefully empty because both stop conditions and time limits are already built into the model. It would be redundant to specify them again here. DO NOT ENTER ANY VALUES OR COMMANDS IN THESE FIELDS.

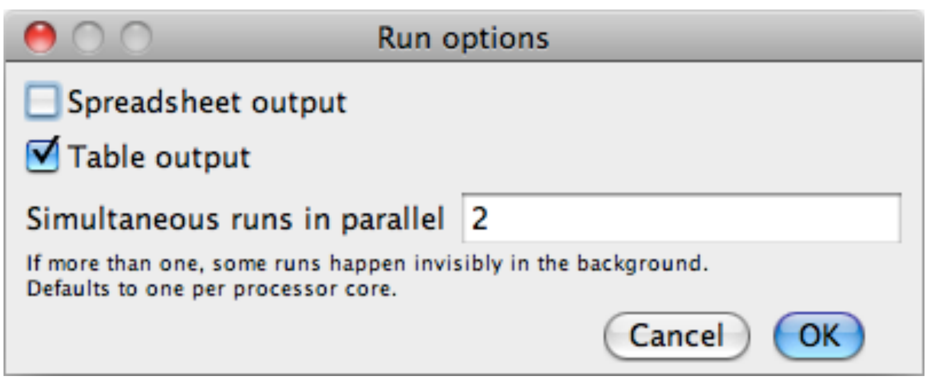
The **Final commands** field can be used to export the model landscape, plots, and world at the end of each model run. The *export-view* command exports the model landscape to an external image file. The *export-plot* and *export-all-plots* commands export either a specific plot or all plots to an external *.csv* file. The *export-world* command exports the values of all variables, both built-in and user-defined, including all observer, turtle, and patch variables and the plot contents. The commands for exporting each feature are as follows:

*export-view (word "Results/" "View" BehaviorSpace-run-number ".jpg")*
*export-plot "Tree Density" (word "Results/" "Density" BehaviorSpace-run-number ".csv")*
*export-all-plots (word "Results/" "All Plots" BehaviorSpace-run-number ".csv")*
*export-world (word "Results/" "World" BehaviorSpace-run-number ".csv")*

The exported files are all written to the *Model* > *Results* folder. Each file type is saved with a common identifier (i.e., ‘view’, ‘plots’, ‘world’) but is numbered according to its place in the BehaviorSpace experiment to prevent file overwriting. The *view* image can be saved with any image extension (*.jpg*, *.png*, *.bmp*, *.tif*, etc) but the plots and world files must be saved with the *.csv* extension.

***Step 5. Run BehaviorSpace Experiment***

Run the chosen experiment by selecting the experiment in the **BehaviorSpace** window and pressing the **Run** button. The **Run Options** window, shown below, will open in the center of your screen.

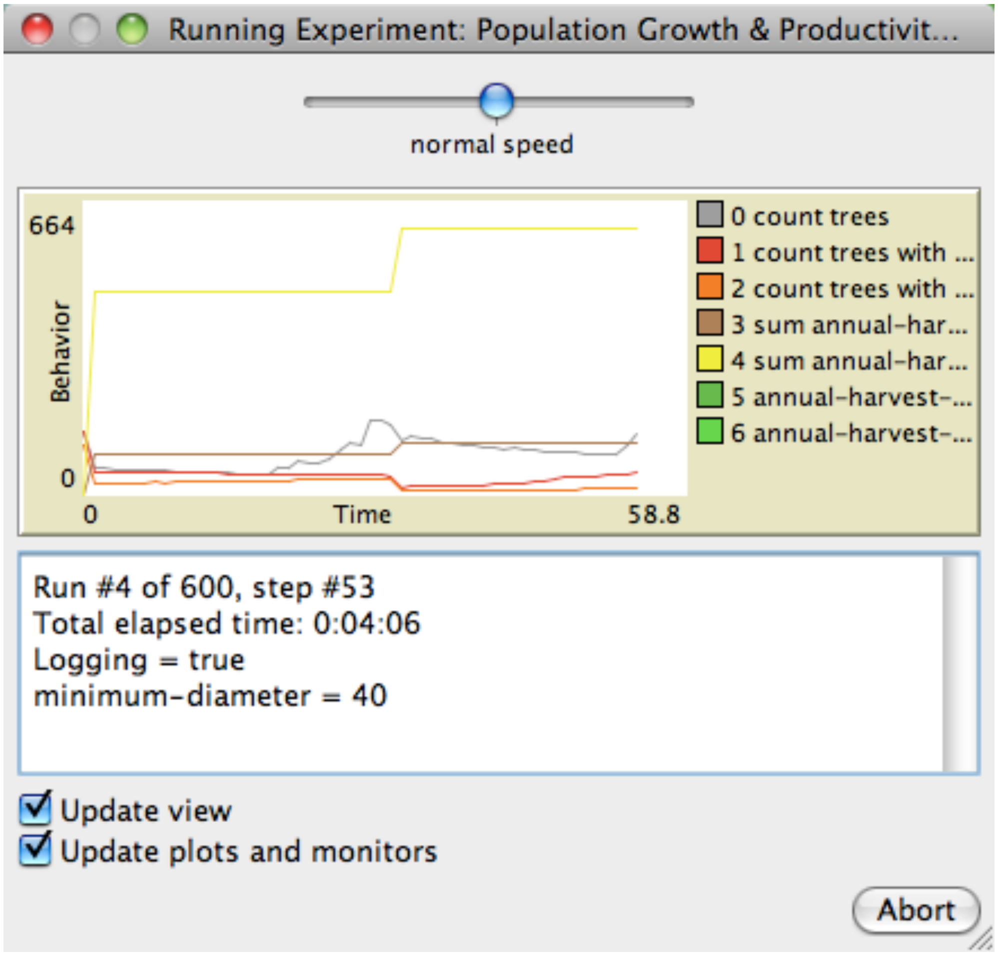



Check the **Table output** option and leave the **Spreadsheet output** option unchecked. Enter ***2*** into the **Simultaneous runs in parallel** field. The **Table output** option creates a more analysis-friendly output and the **Simultaneous runs in parallel** option = 2 maximizes run efficiency.

Press **OK** and save the output file anywhere on your computer. The output file must be saved as a .csv or .xls file. INCLUDE THE .CSV OR .XLS FILE EXTENSION IN THE FILE NAME.

### *Step 6. Determine Run Settings*

After saving the output file, the **Running Experiment** window will open in the center of your screen. This window graphs the population metrics measured during the experiment and tracks the progress of the experiment by reporting the number of completed steps and elapsed time.




The graph will only be shown when measuring every time step; therefore, you will only see this graph if you change the default experiment settings. The graph displays the measure of each population metric over time, where the **Behavior** axis describes each metric. The metrics are color-coded according to the legend on the right.

The output window below the graph tracks the experiment progress. The window reports the number of completed *runs* and the number of completed *steps*, where each *step* represents a year. The total elapsed time is also reported. The experiments take some time to run, so please be patient.

The pace of the experiment can be accelerated by sliding the blue circle to the right, from **normal speed** to **faster speed**. Turning off the visuals will also reduce processing time: uncheck **Update view** and **Update plots and monitors** to further accelerate the experiment run time.

Pressing **Abort** will end the BehaviorSpace experiment. It is not possible to resume an aborted experiment. To continue a BehaviorSpace experiment after pressing **Abort**, you will need to start again from the beginning.

***Step 7. Format Data Output***

The **Running Experiment** window will close when the experiment is completed, returning the **BehaviorSpace** window to the center of the screen. Close the window and browse to the experiment results file. The head of the experiment results file should look like this:

| | A | B | C | D |
|---|---|---|---|---|
| 1 | BehaviorSpace results (NetLogo 5.0.3) | | | |
| 2 | Growth & Yield Model 2.1.nlogo | | | |
| 3 | Population Growth & Productivity: Standard Logging | | | |
| 4 | 01/18/2013 17:09:33:265 -0500 | | | |
| 5 | min-pxcor | max-pxcor | min-pycor | max-pycor |
| 6 | -61 | 61 | -86 | 86 |

This section of the file records basic information about the simulation experiment including: (1) the version of NetLogo run; (2) the name of the model; (3) the name of the experiment; (4) the date and time the experiment was run; and (5) the dimensions of the field site. (Numbers in the above list correspond to the row number in the experiment results file.)

The field site dimensions are reported in terms of NetLogo patches but can be converted to meters by multiplying each value by 10 meters. The length of the X-axis of the site is the sum of minimum (*min-pxcor*) and maximum (*max-pxcor*) X-coordinates. The length of the Y-axis of the site is the sum of minimum (*min-pycor*) and maximum (*max-pycor*) Y-coordinates.

Additionally, we recommend inserting a few lines under the header to record additional information about the simulation experiment. For recordkeeping, it would be useful to record the field site name, area, and dimensions, initial tree abundance and volume, and harvest years.

The rows below the header contain the data from the simulation experiment. The headings can be rewritten for increased clarity based on the following recommendations or on user preference:

| | |
|---|---|
| *[run number]* | Run |
| *Logging* | Logging (on/off) |
| *minimum-diameter* | Minimum Diameter (cm) |
| *retention-rate* | Retention Rate (%) |
| *minimum-density* | Minimum Density (# / 100 ha) |
| *cutting-cycle* | Cutting Cycle (yr) |
| *[step]* | Time (yr) |
| *count trees* | # Trees |
| *count trees with [diameter >= 20]* | # Trees (≥ 20 cm diameter) |
| *count trees with [diameter >= minimum-diameter]* | # Commercial Trees |
| *sum annual-harvest-number* | # Logged Trees |

| | |
|---|---|
| *sum annual-harvest-volume* | Logged Tree Volume ($m^3$) |
| *annual-harvest-number* | Harvest Number List (# / yr) |
| *annual-harvest-volume* | Harvest Volume List ($m^3$ / yr) |
| *pre-post-cut-number* | Pre/Post Harvest Commercial Abundance |
| *pre-post-cut-volume* | Pre/Post Harvest Commercial Volume ($m^3$) |

If you would like to query the model for additional information, please refer to ***Command Line*** and ***Modifying BehaviorSpace Experiments*** below (**sections 12.1 & 12.2**).

***Step 8.  Analyze Simulation Data***

Before analyzing the data, you may be interested in adding a few data columns, such as total density, commercial density, and harvest year statistics.  The abundance (count) values can be converted to density values using the following formula:

$$Density = (Abundance / Site\ Area) * 100$$

where site area is measured in hectares (ha) and density is measured in trees per 100 hectares.

The harvest number and volume lists can be broken into individual years using the *Text to Columns* feature available in most spreadsheet programs.  First, highlight the columns containing harvest lists and use the *Find and Replace* feature to remove the brackets ('[') from the cells. Then, use the *Text to Columns* feature, with data delimited by spaces, to convert the text data to column data.  This will better facilitate the examination of harvest productivity across time.

The post-processing of the harvest value lists can be avoided by using the directions in ***Harvest List Reporters*** of ***Modifying BehaviorSpace Experiments*** (**section 12.2**) to report the harvest list values in individual columns as opposed to a single column list.  Label these new columns accordingly.

The analysis of the experiment data should be performed according to your familiarity with statistics.  A thorough review of statistical analysis is beyond the scope of this User Manual; however, simple statistics, such as average and standard deviation, should suffice most of the time.  For example, a comparison of the average final commercial density to the initial commercial density is a simple but powerful statistical method.

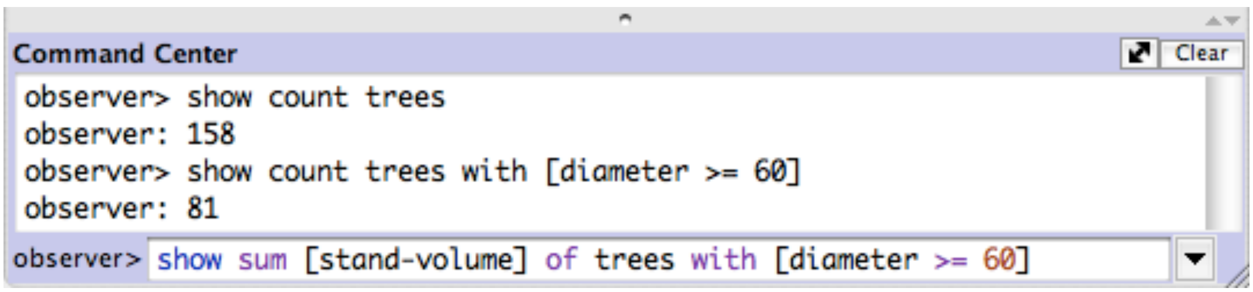
Similarly, calculating the average logged volume from each harvest year provides a simple but powerful summary of harvest productivity over time under different harvest regimes.  A standard deviation of these averages would provide an estimate of confidence.  The BehaviorSpace experiments provide a large sample size and these simple statistics can convey much information about population growth and harvest productivity.

# 12 ADVANCED USERS & NETLOGO RESOURCES

## 12.1 Command Line Code

The following section provides an introduction to using the **Command Center** to query the landscape for information not displayed in the population monitors or plots or harvest monitors.

Commands are entered in the command line window, the small window labeled **observer>**, shown below. The results of the commands are printed in the larger output window labeled **Command Center**.




Copy and paste any of the italicized commands listed below into the command line window. Press *Return/Enter* to run the command. ALWAYS LEAVE THE COMMAND LINE IN OBSERVER MODE. DO NOT SUBMIT COMMANDS IN TURTLES, PATCHES, OR LINKS MODES.

You can access previous commands using the history popup menu, the small downward pointing triangle to the right of the command line window. Press the triangle to see a menu of previously entered commands. Alternatively, you can access previous commands with the *UP* and *DOWN* keys on the computer keyboard, as long as the cursor is in the command line window.

Pressing the **Clear** button in the upper-right corner of the **Command Center** window will erase the contents of the output window. Additionally, the **Command Center** can be resized by grabbing and moving the gray bar at the top of the **Command Center** window.

The following is a list of commands that may be useful to your analysis. For sections with ***bold italicized*** commands (i.e., ***grow-trees***, ***kill-trees***, ***log-trees***, etc.), you must enter the ***bold italicized*** command before entering the other commands. The commands can be modified using the statements at the bottom of the summary to more powerfully query the model results.

**POPULATION STATISTICS**

| | |
|---|---|
| total tree abundance | *show count trees* |
| commercial tree abundance | *show count trees with [diameter >= 60]* |
| first-year-seedling abundance | *show count trees with [seedling? = true]* |

| | |
|---|---|
| total tree volume ($m^3$) | *show sum [stand-volume] of trees* |
| maximum tree basal area ($cm^2$) | *show max [basal-area] of trees* |
| median small tree diameter (cm) | *show median [diameter] of trees with [diameter <= 20]* |
| median tree age (yr) | *show median [age] of trees with [age < 1000]* |
| | |
| initial population abundance | *show y0-tree-density * site-area / 100* |
| initial population density | *show y0-tree-density* |
| initial commercial abundance | *show y0-comm-density * site-area / 100* |
| initial commercial density | *show y0-comm-density* |
| | |
| commercial density (trees / 100ha) | *show count trees with [diameter >= 60] / site-area * 100* |

Note that if you are asking questions about tree ages, be sure to omit trees older than 1000 years, as shown above (see 'median tree age (yr)'). These are the initial trees whose ages are unknown ('1000 years' is simply a marker).

**FIELD SITE STATISTICS**

| | |
|---|---|
| field site area ($m^2$) | *show site-area * 10000* |
| field site area (ha) | *show site-area* |
| field site area ($km^2$) | *show site-area / 100* |
| | |
| field site width (m) | *show world-width * 10* |
| field site width (km) | *show world-width * 10 / 1000* |
| field site height (m) | *show world-height * 10* |

**GROWTH STATISTICS: *grow-trees***

| | |
|---|---|
| specific tree growth rate (cm/yr) | *show [growth-rate] of tree 17* |
| median tree growth rate (cm/yr) | *show median [growth-rate] of trees* |
| fastest growing tree diameter (cm) | *show [diameter] of trees with-max [growth-rate]* |
| | |
| fastest growing tree (tree #) | *show [who] of trees with-max [growth-rate]* |
| smallest basal area tree (tree #) | *show [who] of trees with-min [basal-area]* |
| largest trees: 50$^{th}$ percentile (tree #s) | *show [who] of trees with [diameter > median [diameter] of trees]* |

**HARVEST STATISTICS: *log-trees***

| | |
|---|---|
| last harvest: number of logged trees | *show length cur-logged-volume* |
| last harvest: total logged volume ($m^3$) | *show sum cur-logged-volume* |
| last harvest: largest logged tree volume ($m^3$) | *show max cur-logged-volume* |
| | |
| all harvests: number of logged trees | *show length tot-logged-volume* |
| all harvests: total logged volume ($m^3$) | *show sum tot-logged-volume* |
| all harvests: largest logged tree volume ($m^3$) | *show max tot-logged-volume* |

| | |
|---|---|
| number of trees logged in harvest number x | show item (x - 1) annual-harvest-number |
| volume of trees logged in harvest number x | show item (x - 1) annual-harvest-volume |

number of commercial trees before / after harvests:

| | |
|---|---|
| before | show n-values (length pre-post-cut-number / 2) [item (? * 2) pre-post-cut-number] |
| after | show n-values (length pre-post-cut-number / 2) [item (? * 2 + 1) pre-post-cut-number] |

| | |
|---|---|
| commercial volume before harvest x | show item ((x - 1) * 2) pre-post-cut-volume |
| commercial volume after harvest x | show item ((x - 1) * 2 + 1) pre-post-cut-volume |
| commercial density before / after harvests | show map [? / site-area * 100] pre-post-cut-number |

| | |
|---|---|
| the volume of every tree logged during the simulation | tot-logged-volume |
| the volume of every tree logged during the most recent harvest | cur-logged-volume |
| the total number of trees logged during each harvest | annual-harvest-number |
| the total volume of trees logged during each harvest | annual-harvest-volume |
| the total number of commercial trees before / after each harvest | pre-post-cut-number |
| the total volume of commercial trees before / after each harvest | pre-post-cut-volume |

**MORTALITY STATISTICS: *kill-trees***

| | |
|---|---|
| specific tree mortality probability | show [mort-prob] of tree 17 |
| median tree mortality probability | show median [mort-prob] of trees |
| live tree mortality probabilities | show [mort-prob] of trees with [alive? = true] |

| | |
|---|---|
| dead tree abundance | show count trees with [alive? = false] |
| large dead tree abundance | show count trees with [alive? = false and diameter >= 60] |
| dead tree diameter list (cm) | show [diameter] of trees with [alive? = false] |

**DISTURBANCE STATISTICS: *disturb-trees***

| | |
|---|---|
| landscape disturbance (%) | show count patches with [disturbance? = true] / count patches |
| landscape sweetspot (%) | show count patches with [sweetspot? = true] / count patches |

| | |
|---|---|
| landscape disturbance (ha) | show count patches with [disturbance? = true] * 100 / 10000 |
| landscape sweetspot (ha) | show count patches with [sweetspot? = true] * 100 / 10000 |

**REPRODUCTION STATISTICS: *reproduce-trees***

| | |
|---|---|
| reproductive tree abundance | show count trees with [reproduce? = true] |
| mean reproductive tree diameter | show mean [diameter] of trees with [reproduce? = true] |

| | |
|---|---|
| max large tree fruit probability | show max [fruit-prob] of trees with [diameter <= 30] |
| median fruit production | show median [num-fruit] of trees with [reproduce? = true] |

| | |
|---|---|
| potential seed production | show floor (sum [num-fruit] of trees * seeds-per-fruit) |
| actual seed production | show sum [seedlings] of trees |

**DISTURBANCE / SEEDLING DATASETS**

| | |
|---|---|
| median disturbance area ($m^2$) | *show median disturbance-data* |
| disturbance dataset sample size | *show length disturbance-data* |
| view disturbance dataset | *show disturbance-data* |
| mean first-year-seedling diameter | *show mean seed-diam-data* |
| max first-year-seedling growth rate | *show max seed-growth-data* |

| | |
|---|---|
| list of disturbance area sizes ($m^2$) observed in the field | *disturbance-data* |
| list of first-year-seedling diameters (cm) observed in the field | *seed-diam-data* |
| list of first-year-seedling growth rates (cm/yr) observed in the field | *seed-growth-data* |

Note that distributions for disturbance, seedling diameter, and seedling growth rate can be viewed in the *Model* > *Data* folder. The disturbance size distribution is called *gap-data.csv*. The seedling diameter and growth distributions are called *seed-diam-data.csv* and *seed-growth-data.csv*, respectively.

**EXPORT DATA**

| | |
|---|---|
| export landscape image (.jpg) | *export-view user-new-file* |
| export interface image (.jpg) | *export-interface user-new-file* |
| export output text (.txt) | *export-output user-new-file* |
| export single plot values (.csv) | *export-plot "tree density" user-new-file* |
| export all plot values (.csv) | *export-all-plots user-new-file* |
| export all variables (.csv) | *export-world user-new-file* |

Note that you can name and place exported files anywhere on your computer. Include file extensions as listed in parenthesis above following each export method.

**AVAILABLE STATEMENTS**

| | |
|---|---|
| math statements | *<, >, =, !=, <=, >=* |
| logic statements | *true, false* |
| statistical statements | *max, min, mean, median, modes, with-min, with-max* |
| patch variables | *disturbance?, sweetspot?* |
| tree variables | *who, age, alive?, seedling?, fall-gap? reproduce?, diameter, basal-diameter, basal area, stand-volume, sawn-volume, growth-rate, mort-prob, fruit-prob, num-fruit, seedlings* |

These statements can be substituted for similar statement types in the *italicized* commands provided above. For example, any statistical statement (*max, min, mean,* etc.) can replace a statistical statement in the provided commands. Likewise, any tree variable (*age, alive?, diameter, mort-prob, seedlings,* etc.) can replace a tree variable in the provided commands.

## 12.2 Modifying BehaviorSpace Experiments

***SIMULATION EXPERIMENTS: BEHAVIORSPACE*** (**section 11**) provides a thorough review of the NetLogo BehaviorSpace feature. If you are interested in personalizing the built-in experiments further, or in creating your own experiments entirely, please review the section below.

***Varying Multiple Parameters***

Pre-defined BehaviorSpace experiments are designed to test either a single harvest regime or to test the sensitivity of population growth & yield to a single harvest parameter. It is also possible to examine multiple harvest regimes within a single simulation experiment. This can be achieved by varying more than one harvest parameter in the BehaviorSpace variable settings.

For example, rather than only varying **minimum-diameter**, both **minimum-diameter** and **retention-rate** could be varied using the following code:

*["minimum-diameter" [40 10 80]]*
*["retention-rate" [10 5 30]]*

The BehaviorSpace experiment would simulate each combination of **minimum-diameter** and **retention-rate** for the specified number of repetitions. In other words, each minimum diameter cutting limit, beginning with 40 cm and ending with 80 cm at 10-cm increments, would be simulated with each retention rate, beginning with 10% and ending with 30% at 5% increments.

This design can be implemented with all four harvest parameters to simulate the outcomes of multiple harvest regimes. Although it generates many runs, and therefore requires a lot of processing time, it collects the results in a single spreadsheet for quick analysis.

***Adding New Reporters***

The built-in experiments can also be personalized by adding new reporters or stop conditions to the experiment settings. New reporters can be added from those listed in ***Command Line Code*** (**section 12.1**) although reporters requiring ***bold italicized*** commands will not generate meaningful data since BehaviorSpace reporters are measured at the end of each run.

Copy and paste the **Command Line** reporters (exclude *show* from the reporter) into the BehaviorSpace reporter settings. For example, rather than pasting *show median [diameter] of trees with [diameter <= 20]*, only paste *median [diameter] of trees with [diameter <= 20]*. These reporters will provide additional information when running experiments.

***Harvest List Reporters***

The *annual-harvest-number* and *annual-harvest-volume* reporters print a list of harvest values in two columns as *[item*$_{h1}$ *item* $_{h2}$ *item* $_{h3}$ *item* $_{h4}$ *...]* where each *item*$_{hx}$ represents the harvest value for harvest number *x*. If you prefer that each item receive its own column, you must replace the

*annual-harvest-volume* reporter with the following reporters:

| | |
|---|---|
| *item 0 annual-harvest-volume* | volume of logged trees in harvest 1 |
| *item 1 annual-harvest-volume* | volume of logged trees in harvest 2 |
| *item 2 annual-harvest-volume* | volume of logged trees in harvest 3 |
| *item (1 – X) annual-harvest-volume* | volume of logged trees in harvest X |

The *item* code numbers items in a list from zero onwards so *item 0* is harvest 1, *item 1* is harvest 2, *item 3* is harvest 4, etc. You must enter an *item* reporter for each expected harvest. You can determine the expected number of harvests using the following formula:

*floor (time / cutting-cycle) + 1*

where the 'floor' of a number of harvests is the largest integer less than or equal to the number.

***Pre/Post Harvest List Reporters***

The *pre-post-cut-number* and *pre-post-cut-volume* reporters print a list of harvest values in two columns as $[item_{pre\text{-}h1}\ item_{post\text{-}h1}\ item_{pre\text{-}h2}\ item_{post\text{-}h2} \ldots]$ where $item_{pre\text{-}x}$ and $item_{post\text{-}x}$ represent a population statistic before and after harvest number *x*, respectively. If you prefer that each item receive its own column, you must replace the *pre-post-cut-number* reporter with the following reporters:

| | |
|---|---|
| *item 0 pre-post-cut-number* | number of commercial trees before harvest 1 |
| *item 1 pre-post-cut-number* | number of commercial trees after harvest 1 |
| *item 2 pre-post-cut-number* | number of commercial trees before harvest 2 |
| *item ((X - 1) * 2) pre-post-cut-number* | number of commercial trees before harvest X |
| *item ((X - 1) * 2 + 1) pre-post-cut-number* | number of commercial trees after harvest X |

The *item* code numbers items in a list from zero onwards so *item 0* is the first value, *item 1* is the second value, *item 2* is the third value, etc. You must enter two *item* reporters for each expected harvest. You can determine the expected number of harvests using the following formula:

*floor (time / cutting-cycle) + 1*

where the 'floor' of a number of harvests is the largest integer less than or equal to the number.

***Adding Stop Conditions***

If you are interested in including stop conditions different from the defaults, which stop simulations after the time limit or when all trees die or are harvested, you can enter new conditions in the **Stop condition** prompt. The model stops when conditions become true. For example, if you want to halt simulations after the first harvest, you would enter: *length annual-harvest-number > 0*. Alternatively, if you want to halt simulations when commercial abundance falls below a certain threshold, you would enter: *count trees with [diameter >= minimum-*

*diameter] <= 10*. In this example, simulations would stop when commercial abundance falls below 10 trees.

More information on BehaviorSpace experiments can be found on the NetLogo website or in the NetLogo User Manual. Please see ***NetLogo Resources*** (**section 12.4**) below.

## 12.3 Model Procedure Code

This section provides insight into understanding and modifying the underlying model code.

A fully annotated version of the model code is available in ***APPENDIX E: MODEL CODE*** (**page 68**) and in the **Code** tab of the NetLogo interface. A close review of the code will help you better understand how the model works.

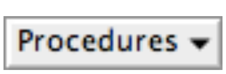
***Procedure Summary***

At the top of the model code you will find basic information about the model: title, authors, funders, landscape dimensions, etc. Throughout the code, gray text on the right side preceded by repeated semi-colons (;;) represents comments provided to help interested users understand how the code operates. This text is not read by the computer.

The first section of functional model code, ***EXTENSIONS, BREEDS, AND VARIABLES***, identifies code extensions and variables used throughout the model. Code extensions activate code types not included in the default language as well as variables used throughout the model to modify trees and the landscape. Breeds identify "trees" as the agents, or individuals, simulated by the model. Global variables are constant values used to make these modifications; these are the only variables we suggest that you modify, as explained below.

***MODEL SETUP***, the second section of code, sets up the model by checking for errors, setting variable values, drawing the landscape, setting the plots and monitors, and establishing the initial population on the landscape. These steps happen in discrete sections of code known as procedures, bounded by the keywords *to* and *end*. Each step is explained thoroughly in the comments.

The third section of code, ***RUN MODEL***, successively grows, kills, disturbs, and reproduces trees on the landscape. This section also resets the trees and landscape in preaparation for the next year of simulation. These steps are also contained within procedures and each procedure is extensively commented in the model code. The fourth and final section, ***EXPORT RESULTS***, contains the code for exporting the results of a single model simulation to a text file.




In the **Code** tab of the NetLogo interface, use the **Procedures** menu to view a list of model procedures and zoom to a specific procedure.

**Procedures** are color-coded according to the following scheme: keywords are **green**; constants are **orange**; comments are gray; built-in NetLogo commands are **blue**; primitive reporters are **purple**; and everything else is **black**.

### *Modifying Global Variables*

It is possible to modify the growth & yield model using alternative data to calculate alternative regressions, but explaining this process is beyond the scope of this User Manual. If you intend to modify model functions, we recommend that you modify only *global variables* (model constants). Global variables are set in the first section of code and are briefly summarized below.

| Variable | Value | Definition |
|---|---|---|
| prop-land-dist | 0.026 | proportion of the landscape disturbed each year |
| seed-shadow-area | 0.91 | area (ha) of a mahogany tree's seed shadow |
| max-num-fruit | 750 | maximum number of fruit per tree |
| seeds-per-fruit | 42.4 | average number of viable seeds per fruit |
| establishment-rate | 0.085 | proportion of seeds surviving to become first-year seedlings |

To change the value of any of these constants, simply replace the old value with a new one. Remember to rename the new model when saving to avoid overwriting the original model. OVERWRITING THE ORIGINAL MODEL WILL FORCE YOU TO REINSTALL THE MODEL.

The ability to redefine global variables is useful for personalizing the model constants to your field site. For example, if you think your site experiences more disturbance, increase the proportion of landscape disturbance (*prop-land-dist*) value. Similarly, if you think the trees in your site have a smaller maximum fruit output (*max-num-fruit*) or produce fewer viable seeds per fruit (*seeds-per-fruit*), you can reduce these values.

## 12.4 NetLogo Resources

NetLogo is a multi-agent programmable modeling environment developed by Uri Wilensky at the Center for Connected Learning and Computer-Based Modeling (Wilensky 1999). If you are interested in learning more about the software, please visit the NetLogo website:
http://ccl.northwestern.edu/netlogo/index.shtml

The website offers resources for learning NetLogo including a User Manual, online dictionary, example models, and publications. The NetLogo Users Group, an online community of NetLogo users, is also available for help and advice: http://groups.yahoo.com/group/netlogo-users/

The NetLogo software comes with a **Models Library**, available in **Files > Models Library** in the NetLogo menu. These models can be used as examples or templates for learning the NetLogo language, modifying the growth & yield model, or creating new NetLogo models.

NetLogo 5.0.3, the version used to run the Big-Leaf Mahogany Growth & Yield Model, can be downloaded here: http://ccl.northwestern.edu/netlogo/5.0.3/. The most recent version of the software can be downloaded here: http://ccl.northwestern.edu/netlogo/download.shtml

# 13 LIMITATIONS & CONSIDERATIONS

The Big-Leaf Mahogany Growth & Yield Model functions are derived from demographic data collected annually from 1995–2010 for nearly 600 mahogany trees and many thousands of seedlings, saplings and pole-sized trees at multiple field sites in southeast Pará and Acre. This comprehensive dataset allows for robust predictions of mahogany population growth & yield outcomes over reasonable time periods. Even so, it is important to acknowledge model limitations that constrain the accuracy and precision of projected outcomes.

First, due to the scarcity of natural regeneration in gap environments, simulated seedling/sapling mortality and growth rates in large gaps are based on data from experimental outplantings across light gradients in large clearings initiated at Marajoara in 1995. These data present *optimistic* estimates of juvenile performance due to manual removal of competing vines and secondary vegetation during the experiments' initial three years.

Second, population outcomes are highly sensitive to disturbance, and the model's disturbance function is derived from data collected during a single year at Marajoara. Because disturbance regimes vary widely across time and space, this data only partially represents the temporal and spatial extent of gap-forming disturbance events necessary for mahogany regeneration and recruitment to adult size.

Finally, the model does not formally incorporate density-dependent population regulation, which may allow *overestimation* of population growth & yield. *Steniscadia poliophaea*, a nocturnal specialist moth, preys more regularly and intensely upon mahogany seedlings in close proximity to large fruiting trees or groups of clumped adults. The population-level influence of this density-dependent seedling predator could be strong if population growth is sensitive to observed reductions in seedling survival and growth. See Norghauer *et al*. references (**section 16**) for more information on this topic. As well, impacts on population growth of the mahogany shootborer, *Hypsipyla grandella*, cannot be directly accounted for in the model due to lack of data addressing this issue. Density-dependent seedling mortality has been shown to reduce population growth rates in other neotropical trees.

# 14 FUTURE MODIFICATIONS

We are interested in using the recently published *R Extension for NetLogo* (Thiele & Grimm, in press: http://r-ext.sourceforge.net/) to increase the robustness of the model regressions, the potential for in-model data analysis, and the functionality of the **Export Results** command.

Both the computer and online models will be updated as new versions of NetLogo are released. Future versions of the model may also be improved according to user feedback and recommendations. Please take the user survey listed on our website: http://www.swietking.org

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# 17 CONTACT US

If you have questions about the model, please email Chris Free: cfree@swietking.org. If you are unable to email, questions can be directed to:

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More information on our research can be found on our website (http://www.swietking.org) or in the publications listed above.

## APPENDIX A: DATA SOURCES

This research program's principal study site, Marajoara, is a forest industry-owned management area in southeast Pará, Brazil (7°50' S, 50°16' W). The site was selectively logged for mahogany between 1992–1994. Model demographic parameters are derived from a sample mahogany population consisting of 358 surviving trees > 10 cm diameter in an area of 2050 ha. These trees were censused annually for survival, stem diameter growth, and fruit production from 1997-2010. Other phases of mahogany's life cycle, including temporal and spatial patterns of seed dispersal, seed germination, and seedling establishment, were quantified in observational and experimental studies at Marajoara. Fruit production data are supplemented by observations of ~325 mahogany trees at three additional sites in southeast Pará and at the Acre/West Amazon site. Because few large (> 100 cm diameter) adult trees survived logging at Marajoara or were available for observation at the other study sites, fruit production data are supplemented with data from Gullison *et al.* (1996).

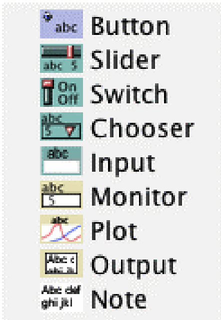
The example populations, discussed at greater length in **section 6.1**, were derived from: (1) a 100%-area inventory of mahogany trees ≥ 20 cm diameter in a 204-ha subplot of the Marajoara field site; (2) a randomly stratified transect survey of mahogany trees ≥ 20 cm diameter in 1035 ha at Marajoara (10% of the total area); and (3) a 100%-area inventory of mahogany trees ≥ 20 cm diameter in 685 ha at the Acre/West Amazon site. Due to selective logging prior to the study, mortality and growth rates may reflect a small post-logging increase.

Due to the scarcity of natural regeneration in gap environments, simulated seedling/sapling mortality and growth rates in large gaps are based on data from experimental outplantings across light gradients in large clearings initiated in 1995. These data present optimistic estimates of juvenile performance due to the manual removal of competing vines and secondary vegetation during the experiments' initial three years.

Canopy disturbances are simulated based on an observed size distribution of gap-forming canopy gaps during 1996–1997 at Marajoara.

# APPENDIX B: MODEL DETAILS & DEFINITIONS

## MODEL FEATURES




**Button**: A button executes instructions when pressed. **Setup**, **Defaults**, **Run 1 Year**, **Run X Years**, **Resize**, **All Definitions**, **Export Results**, **?**, etc., are all buttons.

**Slider**: A slider allows selection from a range of values. The model has sliders for **Time** and **LOGGING PARAMETERS**.

**Switch**: A switch allows a variable to be turned on/off. The **Logging** switch turns the logging function on/off before simulation.

**Chooser**: A chooser allows a user to choose among variable values. The **Populations** chooser allows the user to select between three example populations and three user-defined population options.

**Input**: An input box allows the user to type in a value for a variable. There are two types of inputs: number and text. The **Site-Width**, **Site-Height**, and **Patch-Area** input boxes accept number inputs. The **File-Name** and **Diameter-Attribute-Name** input boxes accept text inputs.

**Monitor**: A monitor displays the value of a built-in expression. The **Site Area**, **Population**, and **Harvest Productivity** monitors report the area of the field site, the density/volume of trees in the initial and current populations, and the number/volume of trees logged during harvests.

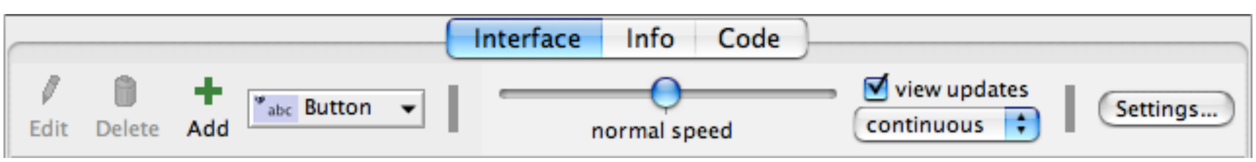
**Plot**: A plot provides a real-time graph of model results. The **Diameter Distribution** plot tracks the size distribution of the population and the **Tree Density** plot tracks tree density.

**Output**: An output provides a text window on the model interface. The **Definitions** output provides definitions of the interface features when the **?** (**Help**) buttons are pressed.

**Note**: A note provides text labels for each section of features. **MODEL SETTINGS**, **LOGGING PARAMETERS**, **YEAR 0 POPULATION**, etc., are all provided to organize and structure the interface.

## INTERFACE DEFINITIONS (see schematic, **page 3**)

## MODEL CONTROL BAR



The **Interface** tab displays model controls and simulations.
The **Info** tab displays basic information about the model.
The **Code** tab displays the workspace where the model code is stored and modified.

**Edit**: This button is only active when a feature is selected on the interface. Pressing the button allows the selected feature to be edited. Use it to modify the range/increment of a harvest parameter.

**Delete**: This button is only active when a feature is selected on the interface. Pressing the button will delete the selected feature. Do not use this button! All features are necessary to the model.

**Add + Button**: In combination, these add buttons, sliders, switches, choosers, inputs, monitors, plots, outputs, or notes to the interface. First press **Add** and then **Button** to choose a feature from the pop-up menu.

**normal speed**: This slider determines the speed of model runs. Slide the round knob left for slower, slide right for faster.

**view updates**: Determines whether landscape updates are shown. When checked, you can view **continuous** updates or **on ticks** updates (that is, at the end of each year). Unchecking **view updates** yields faster model runs.

**Settings**: Determines the size, shape, and resolution of the landscape, and sets the time unit.

## MODEL CONTROLS

### MODEL CONTROLS

| | |
|---|---|
| **Setup** | establishes initial population on landscape |
| **Defaults** | resets harvest and other parameters to default conditions |
| **Populations** | lists selection of example and user-defined initial populations |
| **Site Area** | area of selected site in hectares (ha) |
| **Logging** | determines whether logging is on/off during the simulation(s) |
| **Time** | number of years the model will simulate |
| **Run 1 Year** | runs the model for one year |
| **Run X Years** | runs the model until time limit or all trees are harvested or die |
| **?** | help button returns definitions for a given model section |

### LOGGING PARAMETERS

| | |
|---|---|
| **Minimum-Diameter** | minimum diameter of commercial trees (cm) |
| **Retention-Rate** | retention rate of commercial-sized trees (%) |
| **Minimum-Density** | minimum post-harvest density of commercial trees (trees / 100 ha) |
| **Cutting-Cycle** | number of years between harvests |

### YEAR 0 / CURRENT POPULATION

| | |
|---|---|
| **Total Density** | density of trees ≥ 20 cm diameter in the field site (trees / 100 ha) |
| **Commercial Density** | density of commercial-sized trees in the field site (trees / 100 ha) |
| **Commercial Volume** | volume of timber in the commercial population ($m^3$) |
| **Diameter Distribution** | bar columns = 10-cm diam increments; gray line = commercial diam<br>**black** = initial size distribution; **red** = current size distribution |
| **Tree Density** | vertical gray lines = harvest years<br>**black** line = total tree density; **red** line = commercial tree density |

Commercial-sized trees, or commercial trees, are trees whose diameters are larger than the minimum diameter cutting limit, or *minimum-diameter*. Note that in both **Diameter Distribution** and **Tree Density** plots, no trees < 20 cm diameter are shown.

### HARVEST PRODUCTIVITY

| | |
|---|---|
| **Logged Volume** | volume of trees logged in the most recent harvest ($m^3$) |
| **Total Logged Volume** | volume of trees logged in all previous harvests ($m^3$) |
| **Total # Logged Trees** | number of trees logged in all previous harvests |

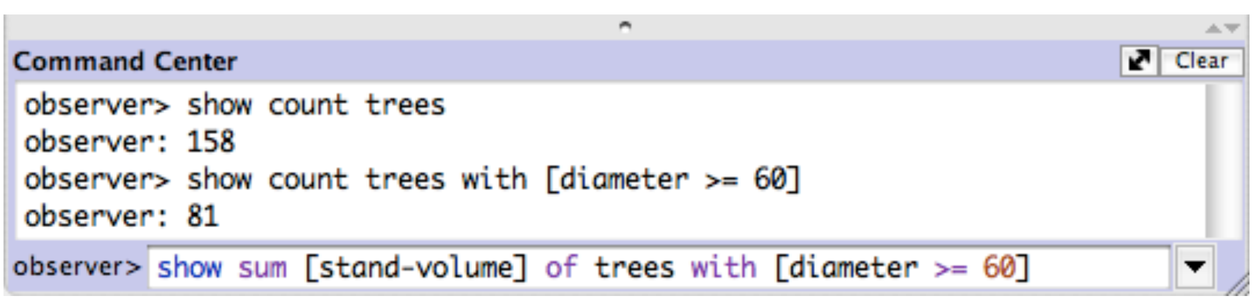
### DATA UPLOAD

| | |
|---|---|
| **File-Name** | name of user data file with diameter and or XY data |
| **Diameter-Attribute-Name** | name of the diameter attribute in the user shapefile |
| **Site-Width** | width (X) of the user field site (meters) |
| **Site-Height** | height (Y) of the user field site (meters) |
| **Patch-Area** | size of the patches on the landscape (pixels) |
| **Resize** | resizes the landscape based on the **Patch-Area** listed |

### DEFINITIONS

| | |
|---|---|
| **All Definitions** | displays the definition/function of all features on the interface |
| **Export Results** | exports simulation results to a user named and located file |

## COMMAND CENTER



The **Command Center** allows commands to be issued directly, without adding them to the model's procedures. This is useful for extracting more specific information about the population than default outputs provide.

**observer>**: This pop-up menu specifies the **Command Center** mode. It can be changed to turtles, patches, or links modes, but should be left in **observer** mode.

 Click on the **History** triangle to browse and select from previously typed commands.

 This button switches the **Command Center** window between vertical window and horizontal views. Other resizing options include: Drag the gray bar separating the window from the interface to a new position. Or, press the small gray arrows above the 'Clear' button to hide the window or make it very large.

**Clear**: Press this button to clear the contents of the **Command Center** window. To clear the **History** pop-up menu, choose 'Clear History' in the menu options.

## APPENDIX C: MODEL FUNCTIONS

This section provides an in-depth review of how the model functions. ***APPENDIX E: MODEL CODE*** (**page 68**) provides a similar review alongside the actual model code. The fully annotated model code is also available in the **Code** tab of the NetLogo interface.

### *Initial Population*

The model begins with an initial population selected by the user and represented on the NetLogo landscape. The landscape is contained within a box where each cell represents a 10 m x 10 m (100 $m^2$) patch on the landscape. Disturbances and seeds dispersed over a landscape edge are not returned on the other side. Because the model is spatial, the arrangement of trees on the landscape is significant in determining simulation outcomes.

At each time step (one year), the following demographic parameters are estimated for each tree based on regression equations derived from field census data: (1) diameter increment (cm $yr^{-1}$); (2) mortality probability; (3) probability of fruit production; and (4) number of fruit produced. The model simulates logging, growth, mortality, disturbance, and reproduction each year with these parameters until the time limit is exceeded or all trees are harvested or die.

### *Growth Function*

The growth function incorporates growth autocorrelation, the tendency of fast-growing trees to remain fast growing, in order to account for past growth history. Diameter increment is estimated as a function of stem diameter using generalized least squares to incorporate an autoregressive error term, accounting for growth autocorrelation over the preceding ten years.

The trees begin the simulation with no growth history, so the residuals, *e1* (1 year previous), *e2* (2 years previous), *e3* (3 years previous), etc., are assigned a random value drawn from the distribution $N(0, 0.48)$. The present year residual, *e0*, is then calculated as follows:

$$e0 = (0.399 * e1) + (0.321 * e2) + (0.081 * e3) + (-0.046 * e4) + (0.130 * e5) + (-0.143 * e6) + (-0.029 * e7) + (0.266 * e8) + (0.190 * e9) + (0.311 * e10) + \sigma \quad (1)$$

where $\sigma \sim N(0, 0.48)$. The residuals are recalculated each time step because, as a year passes, the residual of the previous year becomes the residual of two years before. The residuals are therefore recalculated as *e10 = e9, e9 = e8, …*, *e2 = e1*, *e1 = e0*, and *e0* = the value of the above equation calculated with the new residual values. The growth rate, or diameter increment, of each tree is then calculated using the following equation:

$$growth\ rate\ (cm\ yr^{-1}) = 0.42 + (basal\text{-}diameter * 0.007) - (0.009 * \max(0, basal\text{-}diameter - 40)) + e0 \quad (2)$$

where the *max(0, diameter – 40)* evaluates to zero when a tree is ≤ 40 cm diameter and evaluates to (*diameter – 40)* when a tree is > 40 cm diameter. The resulting diameter increment is added to the current diameter to calculate the new tree diameter. A diameter increment < 0 is reclassed as

0 given the impossibility of negative growth.

### *Logging Function*

The logging function removes eligible trees from the population at the beginning of the simulation and during the subsequent harvest years, as determined by the cutting cycle parameter. The function removes the maximum number of trees larger than the minimum commercial size without violating either retention rate or post-harvest density requirements. Trees selected for logging are randomly stratified across the size distribution of eligible trees. Half of logged trees are allowed to disperse seeds prior to death and all logged trees create canopy gaps proportional to stem diameter based on equations in the ***Mortality Function*** section below (equations 5 & 6).

### *Mortality Function*

The mortality function estimates the probability of mortality as a binary logistic regression of the current year stem diameter and diameter increment using the following equation:

$$\begin{aligned} \textit{log-odds(mortality)} = {} & -0.083 - (4.177 * GR) + (3.705 * \max(0, GR - 0.4)) + \\ & (2.57 * \max(0, GR - 1.5) - (0.575 * BD) + (0.554 * \max(0, BD - 5)) + \\ & (0.027 * \max(0, BD - 25)) + (0.00077 * \max(0, BD - 85)) \end{aligned} \tag{3}$$

where *GR* is the current year diameter increment and *BD* is the basal diameter. The *log-odds* is subsequently used to calculate the probability of mortality using the logit transformation:

$$\textit{mortality probability} = (\exp \textit{log-odds}) / (1 + (\exp \textit{log-odds})) \tag{4}$$

where the fate of each tree is determined by comparing its probability of mortality to a random number between 0 and 1. If the randomly selected number is smaller than the probability of mortality, the tree is marked as dead.

Before its removal from the population, a dead tree is given a 50% chance of dying standing and a 50% chance of dying before reproducing. A tree dying after reproducing will fruit and disperse seeds before being removed from the population, whereas a tree dying before reproducing will be removed from the population without fruiting. A tree dying standing will be removed from the population without creating a treefall gap, whereas a tree resulting in a treefall gap will create a disturbance area according to the following equation:

$$\textit{disturbance area } (m^2) = -25.171 + (1.398 * \textit{diameter}) + (0.02 * \textit{diameter} \wedge 2) \tag{5}$$

where *diameter* is calculated from basal diameter using the following equation:

$$\textit{diameter (cm)} = (\textit{basal diameter} - 0.2842709) / 1.1003362 \tag{6}$$

The radius of the disturbance area is calculated using the equation for the area of a circle, $a = \pi r^2$. The zone of recruitment, that is, the area of the disturbance available for seedling

recruitment, is estimated to be 10 m shorter in radius than the radius of the disturbance area. The resulting disturbance and zone of recruitment areas are constructed on the landscape using the tree as the center of each circular area.

### *Disturbance Function*

The model disturbs the landscape as follows: (1) an initial batch of disturbances is added to the landscape; (2) additional disturbances are then added one at a time until a certain proportion of the landscape is disturbed; and (3) disturbances representing treefall gaps are added last. The model calculates the number of disturbances to add to the landscape in batch based on the area of the field site and the size of the landscape disturbance proportion; larger field sites and larger landscape disturbance proportions receive more disturbances in batch. After placement of this initial group, the model adds disturbances one at a time until the proportion of landscape disturbance matches the specified proportion (default = 0.026). Treefall gaps are placed after the proportion is achieved in order to prevent them from counting towards the background disturbance rate. Disturbance sizes are drawn from a gamma distribution fit to an observed size distribution of gap-forming canopy disturbances (n = 87; shape: 0.6127; scale: 0.0056). All disturbances are circular and the radius of the zone of recruitment is 10 m less than the radius of the whole disturbance; therefore, a disturbance with a radius > 10 m is necessary for recruitment. The zones of recruitment represent the only viable areas for recruitment on the landscape as recruitment does not occur in the forest understory or on the outer edge of canopy disturbances.

### *Reproduction Function*

Fruiting probability is estimated as a binary logistic regression of the current year stem diameter and diameter increment of trees marked as reproductive (all non-seedling trees and 50% of dead mahogany trees) using the following equation:

$$\begin{gathered}\textit{log-odds(fruiting)} = -9.624 + (0.210 * \textit{basal-diameter}) - (0.182 * \\ \max(0, \textit{basal-diameter} - 40)) + (3.201 * \textit{growth-rate}) - (1.165 * \textit{growth-rate} \wedge 2))\end{gathered} \tag{7}$$

which is subsequently used to calculate the fruiting probability using the logit transformation:

$$\textit{fruiting probability} = (\exp \textit{log-odds}) / (1 + (\exp \textit{log-odds})) \tag{8}$$

If fruiting occurs, fruit production is estimated as a function of current year stem diameter and diameter increment in a generalized linear model with a gamma error term. The gamma distribution function is parameterized with the scale and shape factors, *alpha* ($\alpha$) and *lambda* ($\lambda$). The $\alpha$ value is a constant 1.142 while the $\lambda$ value is calculated as a function of the $\alpha$ value and the mean number of fruit. The mean number of fruit for a tree of any given diameter is calculated using the following equation:

$$\begin{gathered}\textit{mean-fruit} = \exp(0.29583 + (0.02453 * \textit{diameter}) + \\ (0.00033 * \textit{basal-diameter} \wedge 2) - (1.744 * 10 \wedge -6 * \textit{basal-diameter} \wedge 3))\end{gathered} \tag{9}$$

These values are subsequently used in the calculation of $\lambda$, which, in conjunction with $\alpha$, is used to parameterize the gamma distribution describing the distribution of fruit production values for a single tree. These two equations are as follows:

$$lambda = \alpha / mean\text{-}fruit \tag{10}$$

$$fruit\ production = gamma(\alpha, \lambda) \tag{11}$$

where fruit production by a given tree is capped at 750 to avoid unrealistically high values.

After fruit production is determined for reproductive trees, these trees disperse their seedlings within the surrounding seed shadow. The number of seedlings after one year is calculated as follows:

$$1\text{-}year\text{-}old\ seedlings = fruit_i * s_{fruit} * f_{surv} \tag{12}$$

where $fruit_i$ is the number of fruit produced by tree $i$, $s_{fruit}$ is the mean number of seeds per fruit, and $f_{surv}$ is the fraction of seeds that germinate and survive to become 1-year-old seedlings. $s_{fruit}$ and $f_{surv}$ are constant values of 42.4 and 0.085, respectively, based on observations at the Marajoara field site. One-year-old seedlings are dispersed evenly within the 0.91-ha circular seed shadow (53.8 m radius) of the parent tree. Because seedling recruitment is only possible within the interior portions of disturbance areas, only seedlings landing in the zone of recruitment (sweetspot) of a disturbance survive. All others die and are no longer tracked in the model.

***Model Reset Function***

The final function in the model procedure resets the trees and landscape before beginning the process again during the next time step (the next year). First, all dead trees and disturbances are removed from the landscape. Second, the tree variables associated with reproduction – fruiting probability, fruit production, and number of surviving seeds – are reset to default values to prevent the values of a reproductive year from carrying over into a non-reproductive year.

# APPENDIX D: VERSION DIFFERENCES

The following document summarizes the changes made to the Big-Leaf Mahogany Growth & Yield Model (Version 1.0) since it was first released in January 2011.

The most significant change is the upgrade from NetLogo 4.1.3 to 5.0.3. This upgrade provides improved handling of foreign characters, a richer **Info** tab, and increased speed and stability.

## VARIABLE NAMES

The following variable names have been updated for increased clarity. The new names in **bold** provide a better summary of function and purpose than the old names (*italics*).

**Global Variables**

- **y0-tree-density** (*y0-tot-density*) – specifies tree density in initial year
- **prop-land-dist** (*prop-dist*) – specifies proportion landscape disturbance
- **disturbance-data** (*disturbance-dataset*) – contains gap size data
- **prob-die-no-repro** (*prob-die-no-seeds*) – specifies the probability of a tree dying before fruiting in the year of its death
- **establishment-rate** (*surv-prob*) – specifies seedling survival rate
- **seed-diam-data** (*seed-diam-list*) – contains seedling diameter data
- **Diameter-Attribute-Name** (*DIAM-Attribute-Name*) **–** specifies the name of the diameter attribute in a user provided shapefile

**Tree Variables**

- **diameter** (*dbh*) – specifies stem diameter
- **basal-diameter** (*diameter*) – specifies stem basal diameter
- **stand-volume** (*volume*) – specifies standing volume
- **mort-prob** (*mort-rate*) – specifies probability of mortality
- **seedlings** (*surv-seeds*) – specifies number of seedlings

## NEW VARIABLES

The following variables have been added to increase functionality of the model.

**Global Variables**

- **small-diam** – specifies minimum size of trees to plot/monitor
- **growth-sigma** – specifies standard deviation of growth residuals
- **num-batch-dist** – specifies how many disturbances to add in batch
- **no-recruit-dist** – specifies non-recruitment distance in canopy gaps
- **large-dist?** – specifies whether large-scale disturbances occur
- **large-dist-prob** – specifies probability of large-scale disturbance
- **large-dist-area** – specifies area of large-scale disturbance

- **seed-shadow-area** – specifies the area of a tree's seed shadow; eliminates *seed-radius*
- **seed-growth-data** – new list contains seedling growth data
- **pre-post-cut-number** – new list contains live tree abundance pre- & post-harvest
- **pre-post-cut-volume** – new list contains live tree volume pre- & post-harvest
- **harvest-ticker (removed)** – removed because of new harvest method

**Tree Variables**
- **age** – specifies age of tree; ages of initial trees are unknown
- **fall-gap?** – specifies whether a tree creates a treefall gap
- **sawn-volume** – specifies sawn volume
- **e4-e10** – specifies growth residuals from 4 to 10 years previous

## MODEL SETUP

**Helper Functions**: The new model has six 'helper functions' to perform calculations repeated throughout the model. These functions help protect against copy/paste errors and simplify the model code. The helper functions are summarized as follows:

| Function Name | Function Purpose | Function Location |
|---|---|---|
| calc-e0 | calculates e0 residual | setup-tree-values; update-residuals; disperse-seeds |
| calc-diam | calculates diameter | calculate-diameter; disperse-seeds |
| calc-basal-diam | calculates basal diameter | setup-tree-values |
| calc-basal-area | calculates basal area | setup-tree-values; calculate-diameter; disperse-seeds |
| calc-stand-volume | calculates stand volume | setup-tree-values; calculate-diameter; disperse-seeds |
| calc-sawn-volume | calculates sawn volume | setup-tree-values; calculate-diameter; disperse-seeds |

**Volume Equation**: The old standing volume equation was replaced with a new equation derived from field studies in Guatemala (Kometter 2011).

**Site Area**: The site area is now specified for example populations and calculated for user populations in the *setup-world* procedure. The specification of example population site areas allows calculation of more accurate population densities.

**World Shapefiles**: The example populations are now constructed using shapefiles that define the extent of the population on the landscape (world). This prevents trees, rivers, and boundaries from being placed against the edge of the NetLogo world boundary.

**User Shapefile Upload**: The code for displaying user shapefiles was modified to fix a bug which halted the model when trees were placed on the world (landscape) edge. The new code expands the world envelope to contain the tree envelope and eliminate the bug.

## PLOTTING

The plotting code is now contained within the plots on the interface. This is the convention for NetLogo 5.0.3 and reduces processing time. The new plotting setup function sets the initial X- and Y-axis sizes to minimize auto-adjusting during model runs.

The *Tree Abundance* plot has been replaced by the *Tree Density* plot. The new plot shows the density of trees per 100 hectares over time using the symbology of the original abundance plot (all trees shown in black; commercial trees shown in red).

## GROWTH FUNCTION

**Growth Residuals**: The growth function now incorporates 10 years of growth autocorrelation and therefore has ten years of growth residuals. In Year 0, the growth residuals of previous years are randomly drawn from a normal distribution. The present-year (*e0*) growth residual is calculated using a new equation derived from the incorporation of new data.

**Growth Rate**: The growth function uses a new equation for determining the annual growth increment. The equation was derived from the incorporation of new data.

## LOGGING FUNCTION

**Year 1 Logging**: The logging of trees in Year 1 now occurs before the growth function (and all others); logging still occurs after the growth function in other harvest years.

**Harvest Years**: The logging function uses a new method for determining whether the present year is a harvest year, comparing the present year to the list of harvest years. This method is more elegant than the old *harvest-ticker* method.

**Stratified Random Logging**: The logging function now stratifies the logging of trees by diameter size class. This change reflects actual logging practices more accurately.

**Minimum Density**: The logging function now prevents the violation of the minimum density requirement. Previously, a bug often allowed an extra tree to be logged in violation of the minimum density parameter.

**Pre/Post Harvest Statistics**: The logging function now records the abundance and volume of commercial-sized trees alive before and after each harvest.

## MORTALITY FUNCTION

**Mortality Probability**: The mortality function uses a new equation for determining the probability of mortality. The equation was derived from the incorporation of new data.

## DISTURBANCE FUNCTION

**Disturbance:** The disturbance procedure no longer includes mahogany treefall gaps in the landscape disturbance rate of 2.6%. A *fall-gap?* tree variable was created to accommodate these changes.

**Batch Disturbance**: The disturbance function now places an initial batch of disturbances on the landscape before adding the disturbances necessary to achieve the specified landscape disturbance rate. This function greatly increases the speed of the model.

## REPRODUCTION FUNCTION

**Fruiting Probability**: The reproduction function uses a new equation for determining the probability of fruiting. The equation was derived from the incorporation of new data.

**Fruit Production**: The reproduction function uses a new equation for determining fruit production. The equation was derived from the incorporation of new data.

**Seed Dispersal**: The reproduction function uses a new method for dispersing seeds; the new method uses the standard approach to uniform seedling dispersal. Although the new function might be slightly slower, it produces a truly random and uniform distribution.

**Seedling Growth Rate**: The seedling growth rates are now drawn from the seedling growth rate distribution; seedling growth rates were previously set to zero.

**Seedling Growth Residuals**: The *e10* growth residual is now calculated from seedling growth rate data. The *e9-e1* growth residuals are set to zero and the *e0* growth residual is calculated using a new equation, derived from the incorporation of new data.

## EXPORT RESULTS

**Export Results Function:** The name of the export results function was changed from *export-data* to *export-results* for increased clarity and accuracy.

**Pre-/Post-Harvest Statistics**: The export function now displays the abundance and volume of commercial-sized trees alive before and after each harvest in the exported text file.

## BEHAVIORSPACE

**View, Plot & World Export**: If exporting a view, plot, or world from a BehaviorSpace experiment, use the *BehaviorSpace-run-number* code in place of the *date-and-time* code when naming the output file. The old code does not work on Windows computers.

## APPENDIX E: MODEL CODE

This section provides a fully annotated copy of the model code. This code is identical to the code in the **Code** tab of the NetLogo interface. The structure of the model code is summarized in ***Model Procedure Code*** (**section 12.3**) and reviewed briefly below.

The head of the model code provides basic information about the model: title, authors, funders, landscape dimensions, etc. The ***EXTENSIONS, BREEDS, AND VARIABLES*** section declares the code extensions and variables used throughout the model. The ***MODEL SETUP*** section sets up the model by checking for errors, setting variable values, drawing the landscape, setting the plots and monitors, and establishing the initial population on the landscape. The ***RUN MODEL*** section successively grows, logs, kills, disturbs, and reproduces trees on the landscape. This section also resets the trees and landscape in preaparation for the next year of simulation. The ***EXPORT RESULTS*** section contains the code for exporting the results of a single model simulation to a text file.

The procedures are color-coded according to the following scheme: keywords are **GREEN**; constants are **ORANGE**; comments are GRAY; built-in NetLogo commands are **BLUE**; primitive reporters are **PURPLE**; and everything else is **BLACK**.